

# Interest-rate and borrowing defense against speculative attack\*

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## Abstract

Our understanding of defense against speculative attacks on fixed exchange rates is incomplete. Though interest rates are often raised to defend a currency, there is almost no formal modeling of interest-rate defense. We present a framework of analysis with special emphasis on signaling when there is incomplete information about the central bank's ability or commitment to defend the fixed exchange rate. The primary focus is on why a high-interest-rate defense may fail even if it raises the cost of speculation and hence temporarily deters speculation. It is shown that the effect of high interest rates under asymmetric information very much depends on the information structure, and hence on the signal that high interest rates send. Depending on what is known, high interest rates may either deter or fuel further speculation. The analysis should be useful in understanding the mixed empirical results on the effectiveness of the interest-rate defense in practice.

## 1 Introduction

Speculative attacks on fixed exchange rates are not new phenomena, but the number and ferocity of attacks in the last few years have made the issue quite current. Numerous countries have witnessed speculative attacks on

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their currencies, leading to massive losses of foreign-exchange reserves and an eventual collapse in investors' confidence in the government's financial liabilities. The immense volume of daily trading in international capital markets and the ease of moving massive sums almost instantaneously make countries seem more at the mercy of speculators than ever before. Yet, even after witnessing many crises over many years, our understanding is far from complete.

Consider some basic questions about defending a fixed exchange rate in a crisis. Can a currency under attack be successfully defended by appropriate monetary policy? Would a defense by measures such as raising interest rates to extremely high levels have averted the currency collapse, and more generally the financial crisis, or would it have only made an inevitable crisis worse? Does a policy of extremely high interest rates send a signal of "toughness" or simply one of panic? Should a country instead engage in massive borrowing of foreign currency in response to a speculative attack?

All of these are key questions facing policymakers about how to defend against a speculative attack, but we lack convincing answers to them. On the empirical side, there is no real consensus about the efficacy of high interest rates in defending against speculative attack. Some countries have used an interest-rate defense successfully, but there have been numerous, often spectacular, failures. Sometimes such a policy appears successful, but the success is short-lived. Other times, raising short-term rates to astronomical levels to defend the exchange rate has seemed to have little effect in deterring speculation. Recently, Kraay (1998) has addressed this issue with more formal econometric techniques, on the basis of which he argues that high interest rates are neither a necessary nor a sufficient condition for preventing a devaluation. His results make him quite skeptical about the value of a high-interest-rate defense.

Even more surprising, given the importance of the questions raised above, is a striking absence of modeling or systematic study of interest-rate defense in the literature on currency crises. This absence is even more striking since interest-rate defenses are often mounted and maintaining high interest rates is a textbook policy often prescribed by the IMF. Moreover, there is really no framework for studying interest-rate defense and for comparing it to alternative strategies. The basic Mundell-Fleming model indicates that with imperfect capital mobility, high domestic currency interest rates are a tool to attract foreign capital and strengthen the domestic currency. However, it gives little real guidance about strategies to defend against speculative attack. Given the lack of theoretical work, it is probably not surprising that there is no empirical consensus on the effectiveness of interest-rate defense.

The purpose of this paper is to provide a model of interest-rate and borrowing defense against speculative attack. The framework stresses optimiza-

tion by both speculators and central banks under asymmetric information, with special emphasis on the fiscal costs of defense. The ultimate aim is to better understand the decision of whether or not to mount a defense, as well as the success or failure of interest-rate defenses. That is, in addition to presenting a general framework that should be applicable, the model should be useful in understanding the ambiguous nature of the empirical results. A further aim of the paper is to help illuminate the conceptual issues involved in an interest-rate or borrowing defense; as such, it includes not simply model construction, but also extensive background discussion, in the hope of making the area accessible to a wider audience.

A main message of the paper is that the relation between raising interest rates and dampening speculative pressures is complex because of the signal inherent in high interest rates. Depending on the information that speculators have, high interest rates may signal either that a government is less able or more able to defend the exchange rate. There will therefore be no simple relation between raising interest rates and the success or failure of speculative attacks.

The plan of the paper is as follows. In the next section, we consider some basic issues in modeling speculative attack and defense, both what issues a model should address and the basic intuition of how an interest-rate defense works. We also review the few papers there are on the interest-rate defense. In Section 3, we briefly review some of the empirical evidence on interest-rate defense. The section is not meant to be comprehensive, but simply to indicate that there is no simple empirical relation between high interest rates and successful or failed defense. In Section 4, we present details of the mechanics of speculative attack and defense. On the basis of this, we present a basic framework for studying interest rate and borrowing defense in Section 5, stressing issues of asymmetric information. Section 6 considers some basic arguments about the effects of interest rate defense as a signal of commitment and as affecting economic fundamentals. Section 7, which is the theoretical heart of the paper, shows how an interest rate defense may fail due to the adverse signal that high interest rates send. In Section 8, we balance this picture with an alternative specification of asymmetric information in which high interest rates send a positive signal. The basic message is that one needs a carefully specified model with imperfect information to understand the effects of high interest rates on speculative attacks, and that such a model indicates that the relation may be quite complex once the signaling aspect of different types of defense is taken into account. Section 9 concludes the paper.

## 2 Basic issues and approaches

### 2.1 *First-generation models*

In Krugman's (1979) seminal paper on exchange-rate collapse, an inconsistency in fundamentals leads to the abandonment of a fixed exchange rate.<sup>1</sup> Current fiscal and monetary policy induces a steady loss in reserves, and is therefore inconsistent with fixed rates. For example, the government is running a deficit, and is financing it by printing money. The rate of monetary expansion is inconsistent with the fixed exchange rate in the long run; in the short run, individuals do not want to hold the higher level of domestic currency and exchange it for foreign-currency-denominated assets. The peg rate must be abandoned when reserves hit a minimum level, which is common knowledge to all market participants. However, the peg collapses not at the date implied by simply extrapolating the steady decline of reserves, but in a speculative attack at some earlier date, namely the first date at which optimal investor behavior implies such an attack will succeed.

Krugman's model of the inevitable abandonment of an unsustainable peg was a major step in understanding how currencies collapse, and it spawned a large literature.<sup>2</sup> However, the view of policymaking it presents is unrealistic in several dimensions. The basic speculative attack model considered in these papers assumes passive rather than optimizing policymakers. In the original Krugman model, for example, the government sticks with current mutually inconsistent policies and abandons the fixed rate reflexively when the critical minimum level is reached. It neither acts aggressively in defending the current exchange rate policy, nor does it adjust its policy in light of external economic and political developments.<sup>3</sup> In fact, abandoning the fixed exchange rate does not simply correspond to reserves hitting a "red line." Theoretically, low reserves is neither a necessary condition for a collapse, as the peg can be abandoned even though reserves are adequate, nor is it a sufficient condition, as reserves can be borrowed. Empirically, the collapse of

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<sup>1</sup>As Krugman (1996) and others have pointed out, the classical model of currency crises is based on the paper by Salant and Henderson (1978), who showed that the attempt to peg the price of gold based on a government-held stock would collapse with a speculative attack that wipes out that stock.

<sup>2</sup>Flood and Garber (1984) formalized the basic Krugman model and hence provided an important advance. Blackburn and Sola (1993) present a summary of first-generation models of this type. Drazen and Helpman (1987, 1988) study the implications of mutually inconsistent monetary, fiscal, and exchange-rate policies more generally, in that policy changes other than letting the exchange rate float are considered in response to the inconsistency.

<sup>3</sup>In the Drazen and Helpman papers, other policies can be adjusted, but there is no government optimization which determines which policies to change. Ozkan and Sutherland (1995) present an optimizing model of policy changes to avoid a currency crisis.

a fixed exchange rate often occurs well before reserves, or some other trigger variable, hits a critical level.

## 2.2 *Three key issues in modeling currency crises and defense*

A more accurate characterization of the behavior of policymakers is that the decision on whether or not to devalue often reflects balancing conflicting objectives. Deteriorating fundamentals are an important part of the story, but the decision to devalue is not always taken because it is literally unavoidable but because of the importance of other objectives. Hence, devaluation may result not only from the technical infeasibility of maintaining the fixed exchange rate, but also from a political decision, the government deciding it is no longer optimal to maintain the fixed parity in light of the costs of doing so because other objectives.

Understanding currency crises therefore requires modeling the optimizing behavior of government, in which its conflicting objectives and how they are weighted are modeled explicitly. Krugman (1996) and others have applied the term "New Crisis Model" to models of currency crises that give a central role to government optimization and that characterize the devaluation decision in terms of choosing between conflicting objectives. As Krugman puts it in characterizing the New Crisis Model. (p. 350): "A government – no longer a simple mechanism like that in the classical model, but rather an agent trying to minimize a loss function – must decide whether or not to defend an exogenously specified exchange rate parity." Examples of this approach include Obstfeld (1994), Drazen and Masson (1994), Masson (1995), Ozkan and Sutherland (1995), Obstfeld (1996), and Bensaid and Jeanne (1997).<sup>4</sup>

A second problem with the basic first-generation model (with some exceptions) is the assumption that speculators know when the peg will collapse. In the new crisis models that stress trading off conflicting objectives, *asymmetric information* often plays a key role. Whether or not peg will be maintained depends on how strongly the government is committed to the fixed rate, but this degree of commitment is not common knowledge. It will also depend on the government's ability to defend the currency, meaning most narrowly its reserve position and ability to borrow reserves, and more broadly its budget situation. These too may not be fully known by speculators. A realistic model of speculators' optimal behavior should have them solving a dynamic signal extraction problem subject to imperfect information about the government's objectives and the evolution of fundamentals. Rational expectations

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<sup>4</sup>A model based on an optimizing government is *not* identical to one with multiple equilibria and the resultant possibility of self-fulfilling crises. A "new" crisis model can have a unique equilibrium, as in Drazen and Masson (1994), whereas a non-optimizing model can have multiple equilibria, as discussed by Krugman (1996).

of devaluation would then be formed by Bayesian updating based on the history of policies and beliefs about shocks the government may face.<sup>5</sup>

A third crucial aspect of speculative attacks not stressed by either first-generation or new crisis models is that many governments defend a fixed exchange rate by raising short-term interest rates or borrowing reserves. Interest rate defense of a fixed exchange rate is often seen in practice, but is largely absent in models of government behavior in the face of speculative attack. (We discuss some exceptions below.) Central banks often use sharp increases in (short-term) interest rates to stem reserve outflows. The basic intuition is simple. Since large speculation against a currency often involves borrowing domestic currency short-term and using the borrowed funds to buy foreign-currency-denominated assets from the central bank, sharply raising interest rates will make such borrowing extremely costly. (Some of the most spectacular examples have overnight interest rates rising to 500-1000%, on an annual basis.) If the interest cost of borrowing rises above the capital gain that speculators expect from a devaluation, they will close their short positions and sell foreign currency back to the bank.<sup>6</sup> (We consider the mechanics more exactly in Section 4 below.) To defend the exchange rate in the face of a speculative attack, the central bank may need to keep interest rates very high for non-negligible periods of time, but such extreme actions would appear to be sufficient to discourage attacks. This is the basic intuition of interest rate defense.

### 2.3 *The costs of defense*

Why then are interest rate defenses unsuccessful? And, why are they not mounted more often? One answer to the second question is inherent in asking the first question. That is, if the interest rate defense is perceived as ineffective, it is not surprising that it is not used more often. The bulk of this paper is devoted to exploring the first question from a theoretical perspec-

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<sup>5</sup>In Obstfeld (1994, 1996), for example, speculator behavior is summarized by their expectations of a devaluation, rationally conditioned on the optimal response of a government with *known* objectives to a common knowledge shock. Drazen and Masson (1994), Masson (1995), and Bensaid and Jeanne (1997) derive the probability of devaluation from Bayesian updating on the policymaker's unknown type, but in models of much simpler speculative behavior and defense than presented here.

<sup>6</sup>There is some skepticism about whether high interest rates can deter speculative attack simply because of the increased cost of borrowing, due to the magnitudes involved. If the horizon over which a devaluation is expected is extremely short, interest rates must be raised to extraordinarily high levels to deter speculation when there is even a small expected devaluation. For example, even if foreign currency assets bore no interest, an expected overnight devaluation of 0.5 percent would require an annual interest rate of over 500%  $((1.005^{365} - 1) \times 100 = 517)$  to make speculation unprofitable. See the discussion in Furman and Stiglitz (1998, pgs. 75-6).

tive. We will argue that high interest rates may fail to dampen speculative pressures because of their signal content. There is another answer to why defenses are not mounted, an answer which is central to any optimizing model of defense of the exchange rate. Interest rate defenses, even if successful, can be quite costly, because of the negative impact of high rates on the domestic economy. Moreover, market participants realize that these costs may make a government unwilling to raise interest rates high enough to defend the currency. (See, for example, Table 4 in Eichengreen and Wyplosz [1993], in which surveyed market traders list this as the primary reason certain governments gave up defending their currencies in the September 1992 ERM crisis.) Four areas of negative impact are generally mentioned. First, there is the negative impact on economic activity, especially when the economy is seen as depressed. Second, in specific cases, there is the negative impact on mortgage interest rates, especially when these rates are directly indexed to money-market rates and defense of the exchange rate requires holding market rates high for significant periods. This argument, for example, characterizes the United Kingdom in 1992, where 90% of home mortgages were at floating rates, linked to short-term market rates. Third, there is the impact of interest rates on increasing the government budget deficit, especially costly if there is already a large deficit. Finally, there is the effect of high interest rates on the corporate and financial sectors, with a risk of destabilizing a fragile banking system. Hence, a social-welfare maximizing policymaker faces a tradeoff in choosing to defend via high interest rates, having to weigh the relative benefits of maintaining the fixed exchange rate against the benefits of maintaining low interest rates. Such a tradeoff should be central to discussions of speculative attacks and currency crises.

A borrowing defense also has costs, though of a different nature. If the fixed rate is successfully defended, then the reserve outflow associated with the attack will be reversed, so that borrowing can be easily paid back. The cost is the interest cost of borrowing, though this may not be large, especially if borrowing is from other central banks under existing short-term financing facilities. However, if there is a devaluation, then closing the short position in foreign currency can be quite costly. It is this which leads central banks to limit their short positions and which constitutes the principal direct cost of a borrowing defense. We consider this in greater detail when we consider the mechanics of a defense.

## 2.4 *Existing models*

Before reviewing the empirical evidence, we briefly review existing theoretical models. Though there are many models of the dynamics of currency crises, those which give an explicit role to an interest rate defense are rare. Lall (1997) presents a model stressing the mechanics of a speculative attack and defense. The behavior of market-making banks in providing forward contracts demanded by speculators (see Section 4 below) is given prominence, with a careful discussion of their strategies when they are uncertain about the degree of central bank intervention. The central bank is modeled as having a loss function which depends on its aversion to expected foreign exchange losses and its desire to smooth interest rates, and an optimal interest rate policy is derived from the central bank's optimization problem. A similar tradeoff will motivate our modeling of the central bank. The paper is quite insightful about the relation between the institutional structure and the choice problems of actors. However, it gives no role to imperfect information about the central bank's objectives, an issue I believe is crucial, nor to the cost of high (as opposed to variable) interest rates.

Drazen (1999) presents a model of interest rate defense under asymmetric information, and not surprisingly, this paper is similar in modeling technique to that one. However, in the earlier paper I do not consider the borrowing defense, and I focus on one specific question, namely the information content of defending the fixed rate (by construction via high interest rates) as a function of the circumstances in which the defense is undertaken. (This is analogous to the question of the information content of capital account liberalization in Bartolini and Drazen [1997b] as a function of when liberalization is undertaken.) Hence, the current paper is more general, for it considers both borrowing and interest rate defenses, as well as a greater variety of information structures, but it is also focused on a different question, namely the information content of different types of defenses. The two papers should be seen as complementary.

Lahiri and Végh (1999) present a carefully worked out dynamic model of interest rate policy during a speculative in a model that differs substantially from the one presented here, in large part because of their different focus. The model is a "first-generation" model in which the fixed rate collapses because the central bank runs out of reserves, rather than due to a decision to stop defending even though this is technically feasible. Asymmetric information plays no role in their analysis. Second, the nature of interest rate policy is quite different, with there being no explicit discussion of the choice between an interest rate or borrowing defense. As in any model of interest rate defense, there must be some imperfect substitutability of assets in order for the central bank to be able to engage in active interest rate policy. Lahiri and Végh assume that both domestic currency and a domestic liquid bond



provide liquidity, where imperfect substitutability is modeled by placing both as separate arguments in the consumer's utility function. Demand for liquid bonds is a function, *inter alia*, of the difference between the interest rate on regular bonds and the interest rate on liquid bonds, the latter controlled by the central bank. Interest-rate policy is choosing by how much to change the interest rate on liquid bonds as a function in changes in the general level of nominal interest rates, where increasing this former rate makes domestic currency assets more attractive. The higher is this response the more active is the interest rate defense, with no response corresponding to a Krugman-type model.

A key result in the Lahiri and Végh analysis is that a more active defense may delay the crisis in the short run, but raising interest rates beyond a certain point will hasten a crisis. What is driving their model is Sargent-Wallace "Unpleasant Monetarist Arithmetic." Interest payments on domestic currency must, via the government's intertemporal budget constraint, be financed by a future inflation tax, the expectation of higher inflation intensifying pressure against the currency a la Sargent-Wallace "Unpleasant Arithmetic." This leads to full defense not being optimal, due to a specific view of the costs of high interest rates.

Flood and Jeanne (2000) present a model based on Flood and Garber (1984). The deviation from uncovered interest parity necessary for interest rate defense to be feasible comes from assuming that domestic and foreign bonds are imperfect substitutes, with the domestic interest rate rising relative to the foreign rate the greater is the quantity of domestic bonds in international investors' portfolios. As in Lahiri and Végh, the key economic relation is the government's intertemporal budget constraint, with a higher domestic interest rate increasing debt service. The fixed rate must be abandoned when fixed (real) tax revenues no longer can cover the real value of debt service at the old exchange rate, so that floating and collection of seigniorage is required to balance the government's budget constraint. An inflow of foreign currency reserves plays no positive role in supporting the exchange rate, so that raising interest rates unambiguously hastens the collapse of the fixed rate.

Another argument that high interest rates may actually weaken a currency has been put forward by Radelet and Sachs (1998) and Furman and Stiglitz (1998) focusing on the effect of interest rates on bank balance-sheet problems. The argument is that high interest rates push highly leveraged borrowers to insolvency, worsening the position of the banks that lend to them and thus inducing foreign lenders to take out their capital. Hence, when the financial sector is "fragile," this "revisionist" view (as some have termed it) holds that high interest rates further destabilize it, leading to a capital outflow and exchange-rate depreciation. Though the revisionist view

is quite important in assessing interest rate defense, neither of the papers argues that it presents a general model of interest rate defense.

In another vein, Garber and Spencer (1995) present a model of the effects of raising interest rates when market participants are engaged in optimal dynamic hedging. It is not meant to be a general model, but to show how optimal hedging strategies may make raising interest rates ineffective as a defense and in fact may lead to perverse effects. Interestingly, they argue that this arises because optimal dynamic hedging programs may mechanically "interpret" an increase in interest rates as signaling a higher probability of a devaluation, thus leading hedgers to sell rather than buy domestic currency (see footnote 9). This is precisely the argument we are making, albeit with a different mechanism underlying the effect.

### **3 Interest-rate defense in practice**

In this section, we quickly review some of the empirical evidence, with an eye towards convincing the reader that a high-interest-rate defense is neither a clear success nor a clear failure. There have been some spectacular defenses, with mixed results.

#### **3.1 *Failed defense***

Sweden is a case often cited of a spectacular defense. In late August 1992 a slow but steady capital outflow began; the Riksbank raised the overnight marginal lending rate to 16% (per annum, as are all rates quoted), and small inflows were recorded. On Tuesday, September 8, Finland announced it was floating the markka as markets in Stockholm were about to open and the krona came under pressure. The Riksbank raised the overnight rate to 24% during the trading day, but outflows continued. The following morning, the Riksbank raised the overnight rate to 75% and announced that it was borrowing 15 billion ECU of foreign reserves. Pressures eased. Over the weekend there was an ERM realignment and the Bundesbank announced it would lower interest rates. Hoping that speculative pressure would ease, the overnight rate was lowered to 20%.

On September 15, there was a new wave of speculative pressure, and the overnight rate was raised once again to 75% on the morning of the 16<sup>th</sup>. European currency markets were in chaos that day. After suffering massive reserve losses that day ("Black Wednesday"), the Bank of England floated the pound. Though speculators turned their focus even more to the krona, the Riksbank was not going to follow suit. It raised the overnight rate to 500% and made clear it planned to raise it further if it thought necessary. Speculative pressures eased, and after four days the Riksbank lowered the

overnight rate to 50%, and then to 40% the following week. It appeared that the interest rate defense had worked.<sup>7</sup>

However, even though outflows stopped, there were no significant inflows. The Riksbank tried to keep market interest rates stable in October and November, but in mid-November speculative pressures resumed and the bank suffered large foreign-exchange losses. It raised the overnight rate to 20% on the morning of November 19, but pressures did not ease and in the afternoon it floated the krona.

Sweden's experience with a temporarily successful defense is not unique. Thailand successfully defended the baht in mid-May 1997, with three-day borrowing rates rising above 1000%, only to face renewed pressure in June and choosing to float the baht on July 2. In other countries, high interest rates are attempted only weakly or soon abandoned. On Black Wednesday the Bank of England raised the minimum lending rate from 10 to 12% in the morning, announced a further increase to 15% a few hours later, but never implemented the increase.

### 3.2 *Successful defense*

However, interest rate defense is not always a failure. On October 20, 1997, the new Taiwan dollar was devalued and the Hong Kong dollar was seen as vulnerable. The Hong Kong stock market lost 23% of its value of the next four days and the HK dollar came under speculative pressure. In response, overnight interest rates were raised from 7% to 250%. Speculative pressure eased and the peg was maintained. Less spectacularly, the French franc came under pressure beginning on September 17, 1992. On September 23 the Banque de France raised the official repurchase rate (*taux des prises en pension*) from 10.5% to 13% and borrowed heavily from the Bundesbank, with the declared intention of convincing the market of its commitment to the fixed parity. The defense was successful.

### 3.3 *Econometric analysis*

Individual country experiences are interesting and informative, but certainly not conclusive. Kraay (1998) presents an econometric analysis aimed to

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<sup>7</sup>There is a subplot here. There was a substantial structure fiscal deficit, with pressure on the krona seen as related to concerns about the deficit. However, political support for extreme fiscal was uncertain, with the prospect of long delay in enacting a fiscal stabilization. The crisis and the Riksbank's response did two things. It made clear to legislators the severity of the problem; and the lull in speculative pressures bought time, with government and opposition leaders agreeing to a crisis fiscal package to reduce the fiscal deficit. One interpretation of the Riksbank's behavior is even more explicitly political—it had no tools available to push for a fiscal consolidation other than raising interest rates to punishingly high levels.

analyze the effectiveness of high interest rates against speculative attack and concludes that there is a lack of strong empirical evidence. He argues that high interest rates are neither necessary nor sufficient to deter speculative attacks. He begins with a sample of 121 successful attacks (defined as a depreciation of over 10% over a month) and 192 failed attacks (defined as a decline of non-gold reserves of over 20% over a month without a significant currency depreciation) from a sample of 75 high- and middle-income countries over the period 1960-97. As an indicator of the interest rate defense he considers both significant increases in the discount rate or its equivalent and a significant tightening of domestic credit, both in real terms. He first calculates two conditional probabilities without any adjustment for country fundamentals. If high interest rates were a necessary condition for successful defense, then the probability that the discount rate increases conditional on the speculative attack failing would be one. (A similar calculation is made for domestic credit restriction.) Instead it is only .56, with the upper bound of a 95% confidence interval only .65. If high interest rates were a sufficient condition for successful defense, then the probability that a speculative attack fails conditional on the discount rate being raised would be one. It is only .64, with the upper bound of a 95% confidence interval only .73. One may argue that these figures give more support to the efficacy of the interest rate defense than Kraay suggests, but it is clear that failures of high interest rates to dampen speculative pressures are not isolated incidents.

Of course, there are serious endogeneity problems, of which Kraay is fully aware. One would not go to a hospital and conclude that modern medicine is ineffective because the patients who get the most intensive treatment are less likely to recover than those who receive only mild treatment. Failure of defense may reflect bad fundamentals, and countries that are highly vulnerable may fight quite hard before devaluing.<sup>8</sup> To try to control for this, Kraay includes a number of measures of the endogeneity of policy in his tests and argues that even controlling for fundamentals, there is no strong evidence that high interest rates reduce speculative pressures. In fact he finds in some of his tests that raising the discount rate appears to lower, rather than raise, the probability that an attack will fail. It is of course extremely difficult to adequately measure the "health" of the exchange rate; nonetheless, the empirical evidence suggests that the effect of high interest rates on speculative pressures is far from clear. Hence, modeling of possible influences is critical.

Hubrich (1999), in a large-sample study similar to Kraay's, does identify significant effects of monetary policy during currency crises. First, he finds that the nominal discount rate is *perverse* related to the outcome of a speculative attack, but that the result is conventional when the monetary

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<sup>8</sup>Conversely, a country that believes it cannot successfully fight off a speculative attack may choose not to attempt a defense, implying a bias in the opposite direction.

policy stance is identified through domestic credit.<sup>9</sup> Hubrich also finds that the stance of monetary policy is *not* significantly more contractionary given a crisis than unconditionally - in other words, countries do not seem to resort to interest rate defense as a rule. Lastly, Hubrich also examines how these results are affected by country characteristics. For example, he finds that countries with low prior reserves are more likely to choose an interest rate defense than countries with high reserves, consistent with a signaling model when reserves are not fully observed, as derived in Section 7 below. It also appears that high-inflation countries are more likely than low-inflation countries to choose an interest rate defense.

## 4 The mechanics of speculative attack and defense

Before presenting a model of interest rate and borrowing defense, we review the mechanics of speculative attack and of defense against attack. We organize the discussion around the two sides of the currency market in a speculative attack, discussing speculators and market-making banks together for reasons that will shortly become clear.

### 4.1 *Speculators*

The key motivating factor in a speculative attack is speculators' belief that the currency will be devalued in the near future with high probability. (We define the exchange rate as the domestic currency price of foreign currency, so that a devaluation is an increase in the exchange rate, with foreign exchange becoming more expensive or domestic currency becoming cheaper.) An individual who holds domestic currency ("crowns") would therefore expect to profit by exchanging it for foreign currency ("dollars") and then repurchasing domestic currency after the devaluation at the new (cheaper) exchange rate. More realistically, a holder of a (short-term) asset denominated in domestic currency may switch to a foreign-currency denominated asset of the same maturity, planning to switch back after the devaluation.

In fact, speculators do not originally hold domestic currency or domestic currency assets. To create a long dollar position they must create a short

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<sup>9</sup>According to Hubrich, Kraay's finding of no clear results stems from his construction of the real interest rate by subtracting ex post annualized inflation from the nominal interest rate. This inflation measure is highly volatile for the majority of emerging economies, and tends to dominate Kraay's overall measure for the real discount rate. When Hubrich uses Kraay's definition for the real discount rate, the results break down for his sample. On the other hand, high nominal rates need not indicate contractionary policy, since high nominal interest rates could simply reflect, say, high devaluation expectations. Domestic credit, if it is related conventionally (that is, negatively) to the adjusted interest rate, does not suffer from this bias.

crown position, for example by borrowing crowns and then buying dollars at the current spot exchange rate. They then plan to unwind this short position at a profit after a devaluation takes place. The conceptually simplest story for studying interest rate defense, and the one we will basically use in the formal modeling, is that speculators borrow domestic currency from the central bank at the discount window and then exchange it for foreign currency at the foreign exchange window. Alternative ways of taking a short crown position have the same net effect, with the central bank being the ultimate party taking a long position in the weak currency. Agents who want to hedge existing short foreign currency positions would balance their foreign exchange exposure with a short position in domestic currency. Hence, though they are not entering the market to take a speculative position, they are on the same side of the market as speculators, and their demand adds to pressure on the domestic currency.<sup>10</sup>

In practice, speculators often take short crown positions via short forward contracts (of at least one month), agreeing to deliver crowns in the future in exchange for dollars "tomorrow" (that is, the speculator sells crowns forward) at an agreed-upon forward rate. To the extent that the currently quoted forward rate is below the expected spot rate, speculators expect to profit, as they can buy the crowns for delivery at a devalued exchange rate. The counterparty to the forward contract is a bank as a market-maker, agreeing to buy crowns for dollars tomorrow at the forward rate. Because of their desire not to be exposed to exchange rate risk, the market-maker bank will try to offset its long crown position by writing an offsetting forward contract (or equivalently, creating a synthetic forward contract, as explained below), balancing the currency and maturity mismatch that the first contract implies.

Who will be the counterparty to the bank? When speculators are selling crowns forward, other banks are in the same position and are also trying to write offsetting forward contracts. (Banks which have not bought crowns forward will similarly be unwilling to provide such contracts and thus open an exposed crown position, especially if they share the view that a devaluation

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<sup>10</sup>Garber and Spencer (1995) examine dynamic hedging strategies (dynamic in the sense that the portfolio is constantly readjusted in the face of changes in interest or exchange rates), where the hedging operation creates a synthetic currency option which hedges the foreign-currency position. A change in interest rates changes the value of the synthetic option and thus induces a readjustment of the portfolio. Garber and Spencer argue that for an optimally constructed dynamic hedge, an increase in the domestic interest rate may induce a hedger to *sell* domestic currency in response, rather than buy, as simple theory would predict! In essence, if the crown interest rate increases and no other variable changes, the hedging program automatically "reads" this change as a higher probability of a devaluation (as embodied in the increase), leading the holder to see crowns to rebalance his position. In other words, the dynamic hedging program reads the increase as a negative signal, automatically performing the inference problem that we study below.

is likely.) Hence, the banking system as a whole is trying to offset a long crown position. Therefore, the ultimate counterparty in the forward market is the central bank as the only agent willing to buy crowns forward. Forward intervention by the central bank thus can provide the credit which ultimately is provided to speculators, with banks acting simply as the intermediary.

For reasons discussed below, the central bank may limit its intervention in the forward market. If the central bank does not supply sufficient forward contracts, the commercial bank must sell domestic currency in the spot market to balance its currency mismatch. The domestic currency that the commercial bank sells spot is usually borrowed at the discount window. Thus, even if speculation is via forward contracts, speculative demand implies that the central bank will be lending domestic currency spot to satisfy demand originating with speculators. Hence, if commercial banks demand offsetting forward contracts in excess of what the central bank is willing to offer, there is a spillover of speculative demand into the spot market, with credit ultimately provided by the central bank in both markets.

A spot sale of crowns eliminates the commercial bank's currency mismatch, but there is still a maturity mismatch in its overall position—the commercial bank is short in crowns today and long in crowns tomorrow, when the forward contract comes due. It eliminates the maturity mismatch through a currency swap, selling one currency for the other today with an agreed upon reverse transaction at some point in the future. Specifically, in the swap transaction, it acquires crowns today in exchange for dollars, with an agreement that it will receive dollars tomorrow (that is, coinciding with the maturity of its original forward contract) in exchange for delivering crowns. The reverse transaction reflects the dollar and crown interest rates over the relevant maturity. This combined spot and swap transactions mean that the commercial bank is essentially selling crowns forward, with the current spot and the interest rates yielding an implicit forward rate.<sup>11</sup> Hence the combined spot and swap transactions create a synthetic forward contract that balance the commercial bank's original forward contract with the speculator.

The above paragraphs indicate that in a speculative attack, one can essentially "net out" commercial banks due to their transactions to balance any positions *vis-à-vis* speculators. The domestic currency lending that is central to the attack is ultimately provided by the central bank. Lall (1997) however points out that commercial banks may limit their forward lending to speculators because they are uncertain of the extent to which the central bank will intervene in the forward market (and want to minimize the risk of not being able to balance their forward exposure by real or synthetic forward contracts). In this case, speculative demand will spill over directly into the

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<sup>11</sup>If  $e$  is the spot rate and  $i$  and  $r$  the domestic currency and forward currency interest rates, the implied forward rate is  $e(1+i)/(1+r)$ .

spot market without the intermediation of market-making banks.

#### 4.2 *The central bank*

We now turn to the mechanics of central bank behavior. What are the options that a central bank wishing to maintain the fixed parity has to respond to a speculative attack? That is, what actions might the central bank take in the face of a reserve drain?

The central bank may supply forward contracts to balance the demand of speculators (or equivalently market-maker banks). If the central bank's purchase of domestic currency forward matches the forward sales of speculators, there will be no need to intervene in the spot market. In practice, a central bank will limit its forward intervention, so that demand spills over to the spot market, since it wants to limit its forward exposure. Supply of forward contracts means the central bank is supplying credit to speculators. If the central bank does not intervene in the forward market to fully offset forward contracts of speculators, commercial banks will enter the spot market and sell crowns to cover their long crown positions, borrowing the crowns they sell from the central bank. Hence, both forward and spot intervention by the central bank imply that the central bank is ultimately supplying the credit to speculators that allows them to attack the domestic currency. That is, the central bank is financing the attack on the currency, no matter whether it responds in the forward or spot market. We return to this point shortly.

If the central bank intervenes in the spot market with its own reserves, it will simply lose reserve until the critical level is reached. If the reserve drain is too great, it must therefore either borrow reserves to meet the drain (the "borrowing defense") or raise interest rates (the "interest-rate-defense") to dampen demand. Borrowing can be done from the banking sector, where in essence the banks are lending the central bank the reserves that speculators have bought and deposited with the banks. Or, a central bank can borrow officially from other central banks or multilateral institutions, often via standing short-term financing facilities. Note that borrowing reserves and intervening in the spot market gives the central bank a similar short position in dollars as supplying forward contracts of the same maturity as the borrowing. Hence, the same arguments that suggest why the central bank wants to limit its short foreign currency position in the forward market (so that demand spills over into the spot market) will serve to limit the amount of borrowing the central bank is willing to undertake. This will be a crucial part of the choice between the borrowing and interest rate defense, and it applies whether the intervention is in the spot or forward market.<sup>12</sup>

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<sup>12</sup>More precisely, intervention with borrowed reserves would be identical to forward intervention if the central bank sterilizes its sales of foreign exchange with an expansion of



As indicated at many points, a standard defense against speculative attack is an increase in the very short-term discount rate in order to make short sales of the currency quite expensive to speculators. This discourages new borrowing as well as roll-over of existing positions, in theory inducing speculators to close their short positions. The increase is meant to raise the cost of speculation above the anticipated capital gain that a devaluation would imply to someone with a short crown position. In addition to the question of the information content of such actions (that is, whether it raises the probability market participants assign to a devaluation), as well as the cost of high interest rates to the economy discussed above, two technical points may restrict the use of this defense. First, as noted, as long as the central bank continues to lend at the discount window, it finances the attack on the currency. Second, the high interest rates affect all borrowers, including those who are simply hedging short crown positions. Restricting domestic credit would analogously hurt all borrowers, not just speculators.

To address the fact that both speculators and nonspeculators are hurt by high interest rates, a central bank will try to channel credit away from the former and towards the latter. If the central bank can identify speculators, they can use differential credit controls and restrictions and charge differential interest rates. For example, the central bank may try to identify "foreign addresses" as speculators (see chapter 4 of the IMF [1997] report on international capital markets) and limit the ability of domestic banks to provide credit or foreign exchange swaps to these addresses. Of course, market participants have strong incentives to circumvent these controls.

Limiting credit gives rise to what Lall (1997) has termed a "classic bear squeeze" on speculators in foreign exchange markets. In a bear squeeze, a market participant attempts to corner the market in a commodity and then manipulate the price upward. This forces short sellers (the "bears") who were betting on a price decline to buy the commodity at a higher rather than lower price when they need to close out their positions, implying large losses for the short sellers and high profits for the agent who cornered the market. In analogy, the central bank restricts the supply of domestic currency that can be borrowed, forcing up the interest rate and inducing an appreciation of the domestic currency. Speculators are squeezed in more than one direction, facing high discount rates, restricted credit (implying the possible need to finance their borrowing at even higher costs), and the possibility of an appreciating domestic currency when they close out their positions. Lall argues that the Bank of Thailand successfully engineered such a squeeze in mid-May of 1997 in their defense of the baht by ceasing forward intervention and baht

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domestic credit to keep the money supply unchanged. In practice, central banks sterilize their intervention, though in our stylized model we ignore any effects of sterilization *per se*.

lending and at the same time forcing banks to severely restrict to offshore borrowers. The market for baht dried up, short-term (three-day) borrowing rates rose to well in excess of 1000 percent (*per annum*), and speculators were forced to close out their positions and sell dollars back to the BOT. On the other hand, such a bear squeeze is difficult, for it generally requires the market to be segmented if there is not to be a severe credit crunch, that is, it requires credit to be unavailable specifically to speculators while other borrowers are not similarly squeezed. A central bank's ability to continue such a squeeze for any length of time is even more doubtful; in the case of the baht, it floated in July of 1997.

## 5 A model of interest rate and borrowing defense

In this section we outline a model of defending a fixed exchange rate by either borrowing reserves or by raising short-term interest rates to keep speculative demand for reserves low. The goal is to derive a tractable model of defense of a fixed exchange rate to allow us to better understand the possible effectiveness of an interest rate defense.

### 5.1 *Defense as a signal*

Our central argument is that a major effect of high interest rates is as a signal of the government's willingness or ability to defend the exchange rate. That is, there are unobserved characteristics of the government that affect the probability that a defense will be mounted or continued, with policy choices being correlated with these characteristics. Hence, given imperfect information about these government characteristics, speculators used observed policy choices to make inferences about them and hence form (that is, update) the probability they assign to a devaluation.

For a signaling story to be complete, one must then show that different "types" of governments will find it optimal to choose different policies, so that policy choice is informative about underlying characteristics. (Formally, one must show that there exists a separating equilibrium.) Given that the data indicate that interest rate defenses have mixed success, sometimes successfully damping speculation, other times seeming only to encourage further speculation, one wants to go a step farther. A useful signaling model must show not only why a vigorous high-interest-rate defense may be read as a negative signal (our primary goal), but also why the signal is read negatively in some cases but not others. In a signaling equilibrium, different government types must find it optimal to choose different policies taking into account their possible negative signal.

## 5.2 *A basic model*

We illustrate our points in a two-period discrete time model. Two periods are chosen to make the exposition as clear as possible. As in Drazen (1999), the framework could be extended to a multi-period, finite-horizon discrete time model. As the previous section makes clear, there are three main "players" in a speculative attack - speculators who attack the currency by shorting it; banks who act as market-makers in providing forward contracts or other instruments to speculators; and the central bank of the country whose currency is under attack.<sup>13</sup> We argued however that to the extent that banks hedge their foreign exchange positions, their role often nets out. Hence we concentrate on two actors, namely speculators and the central bank.

The timing of actions within a period is as follows. For simplicity, we consider a single devaluation rather than a float or repeated adjustments of the peg. At the beginning of each period speculators choose how much to speculate against the currency, on the basis of previously and currently observed variables (to be specified in what follows), the distribution of unobserved variables, the probability they assign to a devaluation at the end of the period on the basis of those distributions, and the interest cost of speculation. The central bank then chooses whether or not to defend the fixed exchange rate, and if so, whether to do so via borrowing or raising interest rates. If it chooses not to defend, it devalues at the beginning of the period. After the central bank has chosen a defense, there is a shock to reserves or some other critical variable which may force a devaluation. Hence, the model includes both devaluation as a policy choice, consistent with second-generation models of currency crisis, and devaluation as unavoidable due, for example, to running out of reserves, as in first-generation models of currency collapse. At the end of the period, speculators exchange their foreign currency for domestic currency and pay off their borrowing. In the case of no devaluation, speculators update the probability of a devaluation in the following period. We now consider the specifics of each step.

## 5.3 *Speculator behavior*

The choice problem of speculators is to choose how much to speculate against the currency as a function of the cost of speculation and the probability they assign to a devaluation over the short term. For studying the dynamics of speculative attack and defense, a model of speculative behavior must have two basic features: it must yield a nondegenerate demand for reserves which

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<sup>13</sup>Foreign official institutions, which lend reserves to the central bank whose currency is under attack, may be seen as a fourth player whose choice problem helps to determine the lines of credit on which the central bank may draw. We "model" them simply by specifying what available borrowing is, as we shall see below.

is a decreasing function of the short-term domestic interest rate and an increasing function of the probability that speculators assign to a devaluation; and it must show how this probability depends on factors that speculators observe, especially the central bank's policy actions when key government characteristics are unobserved. The desire to derive a signaling equilibrium suggests that this demand be derived as simply as possible.

Speculators borrow domestic currency from the central bank at a cost determined by the domestic interest rate  $i_t$  and exchange it for foreign currency, which earns  $r_t$ . Assume the precollapse exchange rate is unity. At the end of the period speculators pay back their borrowing, where the exchange rate in the case of a devaluation is  $1 + \delta$ . We do not explicitly consider forward contracts or other speculative strategies, since the crucial features of speculative behavior embodied in all these strategies, namely, shorting the domestic currency at a cost and being long in foreign currency, are captured in this simple framework. (We argue below that demand for foreign currency by those wishing to hedge will show similar characteristics to that of speculators when high interest rates are taken as indicating a high probability of devaluation.)

To keep the modeling simple, we assume that a speculator does not consider the effect of his own actions on the central bank's decision of whether and how to defend. For simplicity, all speculators have identical beliefs.<sup>14</sup> It is further assumed that a representative speculator can fully adjust his position in a given currency at the beginning of a period. Hence, risk-neutral speculators need consider only the probability of devaluation in the current period, and need not form expectations of the probability of devaluation in future periods to derive their optimal positions. Finally, to maintain the simplicity of working with a parametric interest rate, rather than an interest rate schedule, but at the same time avoid infinite speculative positions, it is assumed that the total flow cost of borrowing is an increasing, convex function  $C(\cdot)$  of the quantity  $i_t D_t$ , where  $D_t$  is the demand to borrow in order to buy foreign exchange reserves. Hence, if the length of a period is  $\Delta t$ , the cost of borrowing over the period is  $C(i_t D_t) \Delta t$ . We further assume that  $C'(0) = 1$ , meaning simply that the marginal cost of borrowing the first dollar is equal to  $i_t$ .

A representative speculator thus chooses  $D_t$  to maximize his expected profit over the period. Expected profit over the period depends on his beliefs about expected devaluation and the interest rate  $i_t$ . The expected devalua-

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<sup>14</sup>Morris and Shin (1998) stress the importance of differences of opinion across speculators in deriving a unique equilibrium. Although differences in beliefs across speculators may characterize some currency crises, our basic points are made most clearly in a model in which all speculators have identical beliefs about the probability of devaluation. Adding differences in beliefs will not change the basic arguments.

tion is  $p_t\delta$ , where  $p_t$  is the current period probability of devaluation  $p_t$  and  $\delta$  is the size of devaluation if one occurs. If periods are short (so that higher order terms in  $i_t$  and  $r_t$  are zero), the expected *rate* of single-period profit (as of the end of the period) is given by:<sup>15</sup>

$$\left(r_t + \frac{p_t\delta}{\Delta t}\right) D_t - C(i_t D_t). \quad (1)$$

Maximization over  $D_t$  implies a first-order condition:

$$r_t + \frac{p_t\delta}{\Delta t} - C'(i_t D_t) i_t = 0. \quad (2)$$

In order to concentrate on the effect of  $i_t$  and  $p_t$  on the speculative demand for reserves, we assume that  $\delta$  and  $\Delta t$  are constant, with  $\Delta t = \delta$ .<sup>16</sup> Hence, speculator behavior yields a demand for reserves in period  $t$  of  $D(i_t, p_t)$ . It is assumed that the market for short-selling domestic currency works as follows. Speculators submit a schedule  $D(i_t, p_t)$  in period  $t$ . The government then decides on the interest rate it will charge.  $D(i_t, p_t)$  is decreasing in  $i_t$  and increasing in  $p_t$ . We postpone till later a discussion of how beliefs on  $p_t$  are formed.

Equation (2) also yields the deviation from interest parity. If  $C(i_t D_t) = i_t D_t$ , then (2) would be the simple uncovered interest parity condition, whereby the domestic currency interest rate would equal the foreign currency interest rate plus the expected rate of depreciation. Here, the two quantities diverge because of the upward-sloping borrowing schedule. Simple uncovered interest parity cannot hold if the central bank is to have the ability to raise the interest rate in order to increase the net cost of speculation. An upward sloping borrowing schedule  $C(i_t D_t)$  allows deviations from interest rate parity in a simple, tractable way.

#### 5.4 Central bank behavior

Observing the demand  $D(i_t, p_t)$ , the central bank decides in each period whether to defend the exchange rate or devalue, and, if it chooses to defend, how to do so. As indicated in the previous section, a central bank has a number of actions available to it in meeting a speculative attack. It may intervene in either the forward or the spot market; if it intervenes in the spot market, intervention may be financed with either its own reserves or with

<sup>15</sup>In the case where  $C(i_t D_t) = i_t D_t$ , expected profits as of the beginning of the period would be  $(1 + r_t)^{-1} [p_t(1 + \delta)(1 + r_t) + (1 - p_t)(1 + r_t) - (1 + i_t)] D_t = (r_t + p_t\delta) D_t - i_t D_t$ . For the more general  $C()$  function, (1) is the analogue.

<sup>16</sup>Note that if the length of the period goes to zero faster than the expected devaluation  $p_t\delta$ , then the demand for reserves becomes infinite.

borrowed reserves; it may restrict domestic credit to speculators or raise the interest rate at which they borrow; or may put controls on credit to specific borrowers or on other foreign exchange operations (such as foreign exchange swaps). Except for the strategy of imposing credit controls, active defense strategies come down to either raising interest rates or borrowing reserves, so we concentrate on those.<sup>17</sup>

Allowing both of these variables to be continuous would both significantly complicate the signaling model and would allow perfect separation of types on the basis of their observed actions. The first makes a multi-period model intractable; the second, though consistent with many signaling models in the literature, is not descriptive of reality. That is, in reality, government actions do not perfectly signal the government's fiscal or reserve position or its overall commitment to the fixed exchange rate. Policy actions are only imperfect indicators of the government's willingness or ability to defend. Both of these factors suggest that the government should choose from a discrete set of actions, with the key decision being whether to raise interest rates significantly or to borrow to defend the exchange rate rather than exactly how much is borrowed or exactly how high the interest rate is raised.

Given these considerations we model a borrowing and interest rate defense very simply by making both of these options simple bivariate choices. In any period the central bank may either raise the interest rate to a level  $i^H$  (the high-interest-rate defense, denoted  $H$ ) or may borrow an amount of reserves  $Z$  (the borrowing defense, denoted  $Z$ ). Hence interest rates are either at a base level  $i^o$  or at  $i^H > i^o$ , where  $D(i^H) < D(i^o)$ . Borrowing of foreign currency reserves is either  $Z$  or 0. We further assume for simplicity that a central bank that defends *either* borrows or raises interest rates, though of course in practice central banks may do both. We also assume that the two types of defense have the same effect on reserves, that is, that  $D(i^H) = D(i^o) - Z$ . A central bank that neither borrows nor raises interest rates in the face of speculative demand is assumed to choose devaluation at the beginning of the period.<sup>18</sup> A central bank that chooses to defend may nonetheless be forced to devalue at the end of the period after the shock to reserves is observed if the shock exhausts the level of reserves inclusive of defensive actions. (That is, for simplicity, we take as zero the critical level of reserves below which a devaluation is required.) The extreme simplicity of the options means that only three possible actions (two defense actions)

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<sup>17</sup>For example, as argued above, a sterilized intervention with borrowed reserves is equivalent to purchasing domestic currency forward.

<sup>18</sup>Alternatively, one could let the central bank that takes neither action  $H$  or  $Z$  simply "wait it out" to see whether they will be forced to devalue. The assumption made in the text is easier to work with and represents the case of a central bank that believed collapse is likely. This would be strictly true if the level of reserves is below  $D(i^o)$ .

must be considered in deriving the central bank's behavior in each period.

A number of aspects of the stark nature of these policy options deserve further justification. The assumption that  $i^H$  and  $Z$  are given rather than choice variables reflects a number of considerations. The first is simple tractability, as discussed above. Second, if  $i^H$  is sufficiently high relative to  $i^o$ , this modeling captures the essential choice in an interest rate defense, namely to raise interest rates to very high (and hence very costly) levels, with the exact value of the high level being less important. Allowing borrowing to take on only two values may be seen as the choice between borrowing massively to defend the exchange rate and choosing to borrow less than the credit limit. This is sufficient to capture the phenomenon of a central bank that believes it may need to devalue finding it optimal to borrow less than its credit lines allow.

The same type of argument indicates why we consider the choice of either an interest rate or a borrowing defense. A primary goal is to show why central banks may use an interest rate defense rather than a borrowing defense, even though it may encourage increased speculation against the currency. This point may be most simply illustrated by assuming that a government chooses one or the other option.

The assumption that the two defense policies have the same effect on reserves, that is, that  $D(i^H) = D(i^o) - Z$ , is also made for simplicity. We argue that it has no substantive effect on our results in the following sense. If one policy gave greater probability, then the critical value of the unobserved variable that induced a switch from one policy to the other would be affected, but the existence of a critical value and the correspondence of policy choices to different sides of the critical value would not be affected.

After the central bank chooses a policy  $H$  or  $Z$ , a stochastic shock is realized which may force a devaluation. For example, when the key fundamental is the level of reserves, there could be a reserve outflow  $\omega_t$  with the exchange rate collapsing if  $\omega_t > R_t + Z_t - D(i_t)$  (where  $R_t$  are reserves of the central bank at the beginning of the period, and by assumption the critical level of reserves below which the exchange rate collapses is zero). Hence, if  $\omega_t$  has a cumulative distribution  $\Omega(\omega_t)$ , the probability of a collapse once a defense has been mounted (but before  $\omega_t$  is observed) is

$$q_t(\cdot) = 1 - \Omega(R_t + Z_t - D(i_t)) \quad (3)$$

where  $q' < 0$ . Analogously, there may be a fiscal shock that necessitates a devaluation, where the probability of such a shock is  $q_t$ , which would be a function of the relevant fiscal fundamental.

## 5.5 Benefits and costs

Having specified the actions available to the central bank, we now consider the benefits and the costs of these actions. As indicated in Section 2, there are four main types of macroeconomic costs to high interest rates, as well as costs to borrowing to defend, and to devaluation itself. A model of the costs of interest rate versus borrowing defense should include: differential costs of the two strategies depending on whether or not there is a devaluation; a dependence of the costs of policies on the state of the economy; and, a possible linkage between actions in one period and costs in subsequent periods, independent of signaling aspects. In the text we consider a general specification of differential costs that could rise from any of the macroeconomic costs of high interest rates; in Appendix 1, we present a specific fiscal model leading to the specification of costs presented in the text. Specifically, we make the following reasonable assumptions. First, if the central bank chooses to defend via high interest rates, these rates must be paid whether or not it is forced to devalue as a result of an adverse shock. A devaluation after an unsuccessful interest rate defense is more costly than abandonment of the fixed rate and devaluation before a defense is mounted, and may have similar effects on the macroeconomic situation to a successful interest rate defense. (Here, they are identical.) Second, in contrast, a borrowing defense may have small effects on welfare if it is successful, but large effects if it is unsuccessful, given the capital loss the government suffers from a devaluation. Basically, the cost of a borrowing defense may be less than an interest rate defense if defense is successful, but greater if it is unsuccessful. It is this ranking of relative costs that is crucial for our results. Given the oft-observed unwillingness of countries to engage in massive borrowing (or the very high costs they incur if they do borrow massively and then devalue), this ranking seems realistic. Moreover, as we shall argue, if borrowing defense was always less costly than an interest rate defense, the latter would never be observed.

Our assumptions about the menu of policy options means that current-period  $\ell$  can take on four possible values, corresponding to: devaluation at the beginning of the period, that is, no defense; interest rate defense (with or without devaluation); successful borrowing defense; and unsuccessful borrowing defense. We denote these as  $\ell^N$ ,  $\ell^H$ ,  $\ell^{ZS}$ ,  $\ell^{ZU}$  respectively, with the ranking

$$\ell^{ZU}(\cdot) > \ell^H(\cdot) > \ell^{ZS}(\cdot) \geq \ell^N, \quad (4)$$

To summarize, in terms of the social loss from high interest rates, the least costly policy is no defense. A successful borrowing defense is the next most costly, as it implies the same level of domestic interest rates, but requires borrowing be paid back with interest. The greater-than-or-equal sign reflects the fact that if  $r^Z$  is small, then  $\ell^{ZS}$  and  $\ell^N$  are approximately equal, rep-



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To summarize, in terms of the social loss from high interest rates, the least costly policy is no defense. A successful borrowing defense is the next most costly, as it implies the same level of domestic interest rates, but requires borrowing be paid back with interest. The greater-than-or-equal sign reflects the fact that if  $r^Z$  is small, then  $\ell^{ZS}$  and  $\ell^N$  are approximately equal, rep-

representing the possibility that a successful defense engineered by borrowing reserves without raising interest rates may have relatively low social cost. A defense via raising domestic interest rates will be costly for the reasons stressed in Section 2 whether it prevents a devaluation or not. The inequality reflects the assumption that foreign-currency borrowing does not drive up domestic interest rates in equilibrium to the same extent as the interest rate defense, that is, the interest rate defense, even if successful, entails a larger social cost than a successful borrowing defense.

The key assumption is that  $\ell^{ZU} > \ell^H$ , that is that an unsuccessful borrowing defense is seen by the government as more costly than an interest rate defense. That is, a borrowing defense is preferred if it is successful but not if it is unsuccessful. The source of this distinction is the significant capital loss on its short foreign-currency position that a central bank will suffer if it borrows massively and then devalues. As was argued in Section 4, it is precisely this loss that leads central banks to limit their short foreign-exchange positions rather than borrow or write forward contracts up to their technical limit. This is the motivation that our model of borrowing or raising interest rates is meant to capture. Moreover, if a borrowing defense was always less costly than an interest rate defense no matter what the exchange-rate outcome, an interest rate defense would never be employed. Hence, observing an interest rate defense implies that governments prefer it under certain circumstances (including foreign currency borrowing becoming prohibitively costly).

There are two other costs associated with abandoning the fixed exchange rate, independent of its fiscal implications. First, to represent the initial decision to commit to a fixed exchange rate, we assume that the government assigns lower welfare to a system in which the fixed rate has previously been abandoned (that is, either a float or a new peg after a devaluation). That is, a devaluation at time  $t$  is associated with lower utility in periods  $t+1$  and after (in a multi-period model). This cost of having previously abandoned the fixed exchange rate is not simply fiscal and is important in comparing the expected costs of choosing a fixed rate system versus an alternative. Specifically, if we denote by  $\ell^V$  (for devaluation) the single-period loss in periods  $t+1$  and after associated with a devaluation at time  $t$ , we assume that  $\ell^V$  is greater than the expected loss at  $t+s > t$  from maintaining (i.e., defending) the fixed exchange rate at the beginning of period  $t$ . We assume that  $\ell^V$  is common knowledge. This assumption motivates the initial commitment to a fixed rate system in terms of its expected benefits; it is also useful in understanding the timing of abandonment of different "types" of governments, as we shall see below.<sup>19</sup>

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<sup>19</sup>In the absence of this assumption, no change in state variables would mean that a government would either devalue immediately or not at all in a multi-period framework.

Second, in addition to the expected benefits of alternative systems, we assume there is a cost that the central bank sees itself as incurring when it breaks its announced commitment to a fixed exchange rate. This cost  $x$  is over and above any effect of devaluation on the economy, a "private" loss to the central bank.<sup>20</sup> This may be a "loss of face" or a political cost associated with breaking its previously announced commitment. Unlike  $\ell^V$ ,  $x$  is a one-time fixed cost incurred in the period the central bank devalues (either by choice or due to insufficient reserves). It differs across governments and is generally not common knowledge. Speculators know only the distribution of possible types  $x$ , as summarized by an initial distribution  $\Gamma(x)$ , initially defined over  $[0, \bar{x}]$ , where  $\bar{x} \leq \infty$ . This distribution will be updated over time, crucial to the role of policy as a signal. We refer to  $x$  at the "commitment type."

If no devaluation has taken place, the central bank's current-period loss function is

$$L(\cdot) = \ell(\cdot) + \zeta(x), \quad (5)$$

where  $\ell(\cdot)$  is as defined in (4) and  $\zeta(x) = x$  if the government devalues; otherwise,  $\zeta(x) = 0$ . The expected present discounted value of the loss associated with different policies will be denoted by  $\Lambda(\cdot)$ , where we define this more precisely in the context of specific applications of this framework.

This framework suggests three types of fundamentals (or government characteristics), where the effect of an active defense on speculative pressures will depend on the evolution of these fundamentals, as well to what extent they are observed. First, there is the weight the government places on defending the exchange rate relative to other objectives. Second, there is the level of reserves, a bank with higher reserves being more able to withstand a speculative attack. The level of reserves is the key variable representing the central bank's *ability* to defend the exchange rate. Third, the government's fiscal position will affect its willingness to raise interest rates to defend the currency. In each case, one may ask about the effects of high interest rates when the fundamental is observed or unobserved.

In most models stressing the deterioration of fundamentals as the driving force of a currency crisis, imperfect information plays a secondary role. In contrast, imperfect information about the government may be central, with policy signaling key unobserved characteristics. We argue that this signaling aspect of high interest rates may be a key to understanding the effects of high interest rates. Depending on what is unobserved, high interest rates may either send a positive or negative signal.

<sup>20</sup>See, for example, Rogoff (1987). This technical apparatus is often used in incomplete-information models to model reputation, as in, for example, Bartolini and Drazen (1997a) on the information content of liberalization of capital controls.

## 6 Some basic arguments

Two basic arguments are often made about the effect of high interest rates to defend a currency beyond their raising the cost of speculation to speculators. First, high interest rates may signal the government's commitment to maintaining a fixed exchange rate and hence deter speculation. Second, the economic costs of high interest rates may themselves induce deterioration of fundamentals and hence encourage rather than deter further speculation. We briefly consider these arguments in turn.

### 6.1 Signaling commitment to fixed rates

In this paper, we explore several signaling arguments. Probably the most widely expressed argument (see, for example, Furman and Stiglitz [1998]) is that high interest rates signal the importance the government places on maintaining the fixed exchange rate relative to other objectives and hence its commitment to defend at all costs. The government's hope is that by signaling this commitment, it will deter future speculation. This argument is explored in detail in Drazen (1999); here, we summarize the basic argument.

For simplicity, suppose the government's only defense option is raising interest rates, so that a defense implies raising the interest rate to  $i^H$ , whereas no defense implies an interest rate of  $i^o$ . All variables are observed except  $x$ , the loss the government places on abandoning the fixed exchange rate. The probability of collapse even with a defense is taken to be an exogenous value  $q$ . Finally, suppose further that in each period there is a shock  $\eta_t$  that affects the loss from a defense, where  $\eta_t$  is observed by both government and speculators at the beginning of period  $t$ .  $\eta_t$  is meant to represent the environment in which defense of the exchange rate takes place.

A government's decision of whether or not to defend the exchange rate takes the form of a simple cut-off rule. Consider a two-period model where one begins with the decision in period two. The expected loss from defending is:

$$q(x + \ell^H(\eta_2)) + (1 - q)\ell^H(\eta_2). \quad (6)$$

(Remember that the loss from high interest rates is incurred whether or not there is a devaluation and that the fixed rate collapses anyway with probability  $q \geq 0$ .) Equating this to  $x$ , the loss from not defending, one obtains a critical value of  $x$  in the second period, namely,

$$\hat{x}_2(\eta_2) = \frac{\ell^H(\eta_2)}{1 - q} > 0, \quad (7)$$

which gives the value of  $x$  for which a government is indifferent between defending and not defending. A government with  $x \geq \hat{x}_2(\eta_2)$  will defend the

exchange rate in period two, while one with,  $x < \hat{x}_2(\eta_2)$  will not defend. Note that though  $x$  is unobserved,  $\hat{x}_2(\eta_2)$  is common knowledge.

The critical value,  $\hat{x}_2(\eta_2)$  also gives the probability of a devaluation as seen by speculators at the beginning of the period. This probability is

$$p_2 = \Gamma(\hat{x}_2|I_2) + (1 - \Gamma(\hat{x}_2|I_2))q. \quad (8)$$

The term  $I_2$  represents the information set of speculators, which is central to the argument.

In period one, there is the same type of cut-off rule, but where the government compares the expected loss over two periods  $\Lambda(\cdot)$  from defending versus not defending. Equating these two would once gain yield a cut-off value of  $x$  (see for example equation (21) below), call it  $\hat{x}_1(\eta_1)$ , with the same property, namely, governments with  $x \geq \hat{x}_1(\eta_1)$  will defend the exchange rate in period two, while one with  $x < \hat{x}_1(\eta_1)$  will not defend. As long as there is some cost to defending, the critical value  $\hat{x}_1(\eta_1)$  will be greater than zero.

The argument that high interest rates may be used to signal a commitment not to devalue and hence deter future speculation can now be simply represented. Using their knowledge of the cut-off level  $\hat{x}_1(\eta_1)$ , speculators update the distribution of possible commitment types based on the policy observed in period one. Specifically, if a successful defense is observed in period one, it is then known that  $x \geq \hat{x}_1(\eta_1)$  and the distribution  $\Gamma(\cdot)$  used in calculating  $p_2$  is truncated at  $\hat{x}_1(\eta_1)$ . In contrast, suppose that policy in period one conveyed no information. (For example, suppose the environment was such that defense was costless.) Then, with no updating of the distribution, the lowest value of  $x$  in period two would be the initial lower bound of 0. Since  $\hat{x}_1(\eta_1) > 0$ ,  $\Gamma(\hat{x}_2(\eta_2)|x \geq \hat{x}_1(\eta_1)) < \Gamma(\hat{x}_2(\eta_2)|x \geq 0)$ , so that the probability assigned to a devaluation in period two given in (8) is lower due to first-period policy serving as a signal of toughness, implying a lower speculative demand.<sup>21</sup>

## 6.2 Endogenous deterioration

In the Krugman model, reserve deterioration is the result of inconsistent macroeconomic policy, but does not depend on any attempt to defend the fixed exchange rate. When high interest rates are used to defend the fixed rate, the deterioration of macroeconomic fundamentals may in fact be the result of these policies. What is meant is not simply that high interest rates make it too costly to maintain a defense, which is a general characteristic of optimizing models of exchange rate defense, but that a "tough" policy currently

<sup>21</sup>Comparing government behavior under asymmetric information about  $x$  with government behavior when speculators know  $x$ , one may note that there are types  $x$  who would choose not to defend in period one if their type were known, but defend when their type is not known in order to discourage speculation in the second period.

leads to a deterioration of macroeconomic circumstances and hence may actually increase the probability that the fixed rate system will be eventually abandoned. This possibility was first stressed by Drazen and Masson (1994), who argued that a tight monetary policy in support of the fixed exchange rate may strengthen the reputation of the policymaker in a model of asymmetric information about his commitment to maintaining fixed rates, but at the same time may actually lower the credibility of the policy. The basic point was that a tough monetary policy will have persistent effects on unemployment and hence may raise the costs of enacting tight monetary policy in the future that would further raise the unemployment rate. Even policymakers strongly committed to fixed rates will devalue if the unemployment costs are high enough; hence, if this persistence effect is strong enough, tough policy raises the probability of a devaluation even as it increases the reputation of the policymaker.

The "persistence-of-tough-policy" effect would also hold for the effect of high interest rates if the government is a net debtor.<sup>22</sup> A high interest rate will worsen the fiscal balance, this effect being greater the higher is outstanding stock of debt. Hence, debt carried over will increase, yielding the intertemporal linkage that Drazen and Masson stressed. To complete the argument, one then needs to relate higher debt at  $t + 1$  to a higher probability of collapse of the fixed rate system. One possibility is to assume a fiscal structure yielding "Unpleasant Monetarist Arithmetic" following Sargent and Wallace (1981). That is, suppose that  $g_t$  is fixed and  $\tau$  represents seigniorage revenues which may vary over time. Restrictive monetary policy driving up interest rates and hence debt service today requires higher seigniorage revenues tomorrow to service the debt. This implies higher expected inflation tomorrow which puts more pressure on the fixed rate. As discussed above, Lahiri and Végh (1999) consider such a mechanism in a first-generation model.

These models suggest a first reason why an interest rate defense may be unsuccessful. Even when there is no signal involved (or even more so when an interest rate defense signals commitment to defending the exchange rate), an interest rate defense may lower the credibility of the fixed rate by worsening the economic situation in a known way. Hence, if a country is known to have weak fundamentals and a high-interest-rate policy is seen as further weakening them, an interest rate defense may be counterproductive. This is true both for weak fiscal fundamentals and for other structural weaknesses. It also suggests one reason why an interest rate defense is not mounted, as in the case of the United Kingdom in September 1992.

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<sup>22</sup>Drazen and Masson (1994) mentioned this possibility, but did not pursue it.

## 7 The interest-rate-defense as a negative signal

We now turn to a model of asymmetric information in which the interest rate defense sends a negative signal and hence dampens speculation today at the cost of higher speculative pressures in the future.

### 7.1 Set-up

To illustrate the basic point, we consider a two-period version of the basic framework with the following imperfect information structure. Two characteristics of the government are unknown to speculators: initial reserves  $R_1$  and commitment type  $x$ . The collapse probability  $q_t$  represents a stochastic endogenous reserve drain  $\omega_t$ , as in equation (3).

To repeat, the sequencing of actions within a period is: speculators choose a demand schedule  $D(i_t, p_t)$ , after which the government chooses its policy; a reserve shock is then observed, which forces a devaluation if it drives reserves below zero; and, at the end of the period, all borrowing is paid back. Foreign borrowing is done only to defend the exchange rate and is paid back fully at the end of the period. Reserves held by the central bank are assumed to pay no interest. As discussed above, we assume that both the borrowing and the interest rate defense yield the same probability of collapse for given  $R$ , so that  $q^H = q^Z = q(R_t - D_t)$ .

### 7.2 Period two-government behavior

We solve the model backward from period two, leading to a Perfect Bayesian Equilibrium. We begin with the decision of a government of type  $(x, R_1)$  of how to defend. With a probability  $q_2$  of a devaluation and using the fact that the loss from an interest rate defense is the same whether or not there is a devaluation, the expected loss from an interest defense is:

$$q_2(x + \ell^H) + (1 - q_2)\ell^H = q_2x + \ell^H, \quad (9)$$

where  $q_2$  is a decreasing function of  $R_2$  as given by (3). The expected loss from a borrowing defense is:

$$q_2(x + \ell^{ZU}) + (1 - q_2)\ell^{ZS} \quad (10)$$

where by assumption  $q_2$  in the two expressions is identical. Equating (9) and (10), we obtain a critical value of the devaluation probability, call it  $\hat{q}_2(\cdot)$  such that the government is indifferent between the two policies, namely:

$$\hat{q}_2(\cdot) = \frac{\ell^H - \ell^{ZS}}{\ell^{ZU} - \ell^{ZS}}, \quad (11)$$



which by (4) is strictly between 0 and 1. Using (3) giving a relation between  $q$  and  $R$ , (11) defines a critical level of reserves such that the central bank is indifferent between the two defense policies, namely:

$$\hat{R}_2 = q^{-1}(\hat{q}_2[\cdot]). \quad (12)$$

For  $R_2 \geq \hat{R}_2$ , (4) implies that the expected loss from an interest rate defense in (9) exceeds the expected loss from a borrowing defense in (10), so that a borrowing defense is chosen, while for  $R_2 < \hat{R}_2$ , the ranking of the expected loss from the two policies is reversed, so that the interest rate defense is chosen. Note that the ranking of these choices is independent of  $x$ .

Intuitively, this policy choice is driven by the differential cost of a borrowing defense relative to a high-interest-rate defense depending on whether the central bank expects to devalue or not. If the central bank thinks a devaluation is likely, then it prefers a high-interest-rate defense, as a borrowing defense entails an expected capital loss on its short foreign-currency position. Conversely, if the government thinks that the defense is likely to be successful, then a borrowing defense is seen as having a lower cost than an interest rate defense. This result seems intuitively quite plausible, and the model was constructed to highlight what it depends on. Since the probability of the defense being successful depends on the level of foreign exchange reserves, the choice of what kind of defense is related to the level of reserves.

Now, consider the choice of whether or not to defend the exchange rate, conditional on the decision given in the last paragraph on how to defend. Consider first the case in which  $R_2 < \hat{R}_2$ , so that an interest rate defense is used if defense is chosen. No defense entails a loss of  $x + \ell^N$ . Equating this to (9), we obtain a critical value of  $x$  for each  $R$ , such that a central bank is indifferent between defending and not defending:

$$\hat{x}_2^H(R_2, \cdot) = \frac{\ell^H - \ell^N}{1 - q_2} \quad (13)$$

where the  $H$  indicates that no defense is being compared to the high-interest-rate defense. A central bank with  $R_2 < \hat{R}_2$  will then choose to defend if  $x \geq \hat{x}_2^H$  and will choose not to defend if  $x < \hat{x}_2^H$ . with respect to  $R$ , we find

$$\frac{\partial \hat{x}_2^H}{\partial R_2} = \frac{q'(\cdot) \hat{x}_2^H}{1 - q_2} < 0 \quad (14)$$

so that the critical value is falling with an increase in reserves, meaning more  $x$  types would choose to defend. Note also that for  $R_2$  sufficiently small, all finite  $x$  types would choose no defense.

When  $R_2 \geq \hat{R}_2$ , so that the borrowing defense would be used to defend, equating the cost of no defense to (10) yields a similar critical value such

that central bank is indifferent between defending and not defending:

$$\hat{x}_2^Z(R_2, \cdot) = \frac{q_2 \ell^{ZU} + (1 - q) \ell^{ZS} - \ell^N}{1 - q_2} \quad (15)$$

where the  $Z$  indicates that no defense is being compared to the borrowing defense. As before, types with  $x$  greater than or equal to the critical value choose to defend, whereas those with  $x$  less than the critical value do not. Over all  $R_2$ , the relevant critical value  $\hat{x}_2(R_2)$  then depends upon which regime is relevant. Differentiating (15) with respect to  $R$ , we find

$$\frac{\partial \hat{x}_2^Z}{\partial R_2} = \frac{q'(\cdot)(\hat{x}_2^Z + \ell^{ZU} - \ell^{ZS})}{1 - q_2} < 0 \quad (16)$$

Comparing (14) and (16) we see that at  $\hat{R}_2$ , where (9) equals (10), so that  $\hat{x}_2^H = \hat{x}_2^Z$ ,  $\partial \hat{x}_2^Z / \partial R_2 < \partial \hat{x}_2^H / \partial R_2$ . Hence, the optimal choice of second period policy as a function of type  $(x, R_2)$  is fully summarized by Figure 1.

### 7.3 Period two-speculator behavior

The decision problem of the representative speculator is to choose a level of speculation as a function of the interest rate he faces and the probability of a devaluation, where this probability depends on the distribution over types conditional on first-period policy actions. Using (2), we write second-period demand as  $D(i_2, p_2)$ , where  $D$  is decreasing in its first argument and decreasing in its second argument.

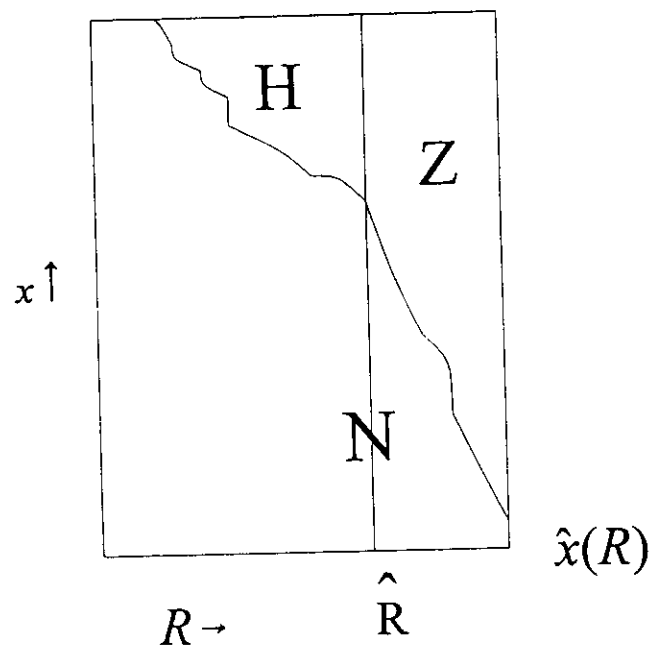
The probability that speculators assign to a devaluation in period two on the basis of observed policy in period one is:

$$p_2 = \int_{R_2} (\Gamma[\hat{x}_2(R_2)|j_1] + (1 - \Gamma[\hat{x}_2(R_2)|j_1])\Omega(R_2)d\Psi(R_2|j_1) \quad (17)$$

where  $\Omega(R_2)$  is the probability of a shock forcing devaluation conditional on  $R_2$  from (3),  $\Gamma[\hat{x}_2(R_2)|j_1]$  is the cumulative distribution of commitment types conditional on the policy observed in the first period, denoted  $j_1$ , and  $\Psi(R_2|j_1)$  is the cumulative distribution of reserves conditional on the policy observed in the first period. Lower reserves make a devaluation more likely both because a given  $x$  type is less likely to defend and because having chosen to defend he is more likely to be forced to devalue after the shock  $\omega$  is realized.<sup>23</sup>

<sup>23</sup>One may note that in a separating equilibrium, a high interest rate reveals that the government will defend. Hence, if a speculator's demand is conditional on the interest rate, the value of  $p_2$  that a speculator uses in calculating his demand for reserves will be simplified.

**Figure 1 – Optimal  
Defense Decisions**



#### 7.4 Period one—government behavior

We now consider the period-one problem. Our interest is in deriving the effect of the period-one policy on expectations of a devaluation in period two. Specifically, we are interested in showing that an interest rate defense in period one is a signal of low reserves and hence increases the probability that speculators assign to a devaluation in the second period.

The government's problem is now to choose policies in the first period minimizing expected loss over both periods. Consider first the choice of how to defend the exchange rate. Choosing the high-interest-rate defense has a two-period expected loss of:

$$\Lambda^H(x, R_1) = q_1(x + \ell^H + \beta\ell^V) + (1 - q_1)(\ell^H + \beta El_2(j_1 = H)). \quad (18)$$

where  $j_1 = H$  indicates the first-period policy choice. Choosing the borrowing defense has a two-period expected loss of:

$$\Lambda^Z(x, R_1) = q_1(x + \ell^{ZU} + \beta\ell^V) + (1 - q_1)(\ell^{ZS} + \beta El_2(j_1 = Z)) \quad (19)$$

For a commitment type  $x$ ,  $El_2(j_1 = H, Z)$  depends on the reserves  $R_2$  carried over. Since both policies have the same net effect on reserve loss (remember that  $D(i^H) = D(i^o) - Z$ ), this in turn depends on  $R_1$ .

The difference in the expected loss may be written

$$\begin{aligned} \Lambda^H(\cdot) - \Lambda^Z(\cdot) &= [\ell^H - (q_1\ell^{ZU} + (1 - q_1)\ell^{ZS}) \\ &+ \beta(1 - q_1)(El_2(j_1 = H)) - El_2(j_1 = Z)]. \end{aligned} \quad (20)$$

The difference in expected loss is made up of two components. There is the difference in current-period expected loss, the first term in square brackets. Second, there is the expected second-period loss, namely,  $El_2(j_1 = H) - El_2(j_1 = Z)$ . (Remember, that both policies have the same effect on  $q_1$ .) Expected second-period loss is affected by first-period policy because of their effect on speculators' estimate of  $p_2$  which affects speculative demand in the second period. The estimate of  $p_2$  in turn depends on expectations about  $R_2$ , as in (17). The signaling effect may be summarized in the following proposition:

**Proposition 1:** High-interest-rate defense in the first period leads to a higher expected loss in the second period due to a negative signal about available reserves, implying a higher value of  $p_2$ . That is,  $El_2(j_1 = H) > El_2(j_1 = Z)$ .

Proof in Appendix 2

The proof is by contradiction, and its structure reveals the intuition of the

proposition. As in period two, the current period loss in the first period alone implies that governments with low reserves in period one choose policy  $H$  while those with high reserve choose policy  $Z$ . Suppose that policy  $H$  nonetheless sends a signal of higher reserves in period two, that is,  $E\ell_2(j_1 = H) - E\ell_2(j_1 = Z) < 0$ . If this term is not too strong, then governments with low reserve still choose policy  $H$  whereas those with high reserves choose policy  $Z$ . Since reserves are correlated across periods, observing policy  $H$  would lead to the expectation of lower reserves in period two, hence higher probability of devaluation and higher expected loss, implying a contradiction. Alternatively, if the positive signal of  $H$  is sufficiently strong, then all reserve types choose  $H$ , so that there is no signal content of policy  $H$ , once again a contradiction.

As in the second period, we may characterize the first-period decision on how to defend in terms of a critical level of reserves  $\hat{R}_1$  such that a central bank with  $R_1 \geq \hat{R}_1$  will choose a borrowing defense, while a central bank with  $R_1 < \hat{R}_1$  will choose an interest rate defense. Hence, in the choice between the high-interest-rate defense and the borrowing defense, high interest rates signal low reserves so that this defense today increases speculative pressures tomorrow. Governments with low reserves choose this policy even though they are aware of the negative signal, because their low reserve position makes them more likely to devalue in response to an adverse shock, thus leading them to prefer not to take a short position in foreign currency. Hence, a high-interest-rate defense dampens speculation today at the cost of encouraging it in the future.

To complete the description of first-period optimal government behavior, we consider the choice of whether or not to defend the exchange rate, conditional on the decision on how to defend. The argument mirrors that given for the decision of whether or not to defend in the second period. Consider the case where  $R_1 < \hat{R}_1$ , so that an interest rate defense is used if defense is chosen. No defense entails a loss of  $x + \ell^N + \beta\ell^V$ . Equating this to (18), we obtain a critical value of  $x$  in period one such that a central bank is indifferent between defending with high interest rates and not defending:

$$\hat{x}_1^H(R_1, \cdot) = \frac{\ell^H - \ell^N}{1 - q_1} + \beta(E\ell^2(j_1 = H) - \ell^V). \quad (21)$$

A similar expression may be derived for the case in which where  $R_1 \geq \hat{R}_1$ , so that defense is via borrowing, analogous to the derivation for period two, yielding a critical value  $\hat{x}_1^Z(R_1, \cdot)$ . Taking the relevant critical value, denoted simply value  $\hat{x}_1(R_1, \cdot)$ , a central bank with  $x \geq \hat{x}_1(R_1, \cdot)$  will defend, while one with  $x < \hat{x}_1(R_1, \cdot)$  will not defend and devalue at the beginning of the period.

To compare with  $\hat{x}_1(R_1, \cdot)$  in (13) with  $\hat{x}_2(R_2, \cdot)$  in (21), note that the

second term in (21) is negative under the assumption that the expected loss from a fixed exchange-rate system is less than loss from a float or a new peg after a devaluation. We assume that  $\ell^H$  and  $\ell^N$  are independent of the level of reserves, and hence are equal across periods. Comparing (21) to (13), we then see that  $\hat{x}_t$  will be rising over time if  $q_t$  does not significantly fall over time. This will be the case for a central bank losing reserves (so that  $q_2 > q_1$ ).

### 7.5 *Period one—speculator behavior*

In the first period, the speculative demand is described by the same function as in period two, namely,  $D(i_1, p_1)$ , as given implicitly by (2). The probability of a devaluation  $p_1$  is simply the prior, with speculative demand being greater the greater is the prior probability that speculators assign to a devaluation. This prior is rationally derived from the initial distributions for  $x$ ,  $R_1$ , and  $\omega_1$ , conditional on government's optimal behavior. It is given by

$$p_1 = \int_{R_{21}} (\Gamma[\hat{x}_1(R_1)] + (1 - \Gamma[\hat{x}_1(R_1)])\Omega(R_1))d\Psi(R_1) \quad (22)$$

where the distributions are defined as above after (17).

Period-one government policies will be used to update this prior to obtain  $p_2$ , as given in (17). The observation of a choice to defend at  $t$  leads speculators to believe the government is more committed to defending the fixed exchange rate, that is, to update the distribution of commitment types, truncating the distribution  $\Gamma(x)$  at  $\hat{x}_t$ , as described in the previous paragraph. This updated distribution of  $x$  was denoted  $\Gamma[\hat{x}_2(R_2)|j_1]$  in (17). The updated distribution of reserves conditional on how the government defended and the observation of  $\omega_1$  is given by

$$\Psi(R_2|j_1 = H) = \Psi(R_1 - D(i_1, p_1) - \omega_1 | R_1 < \hat{R}_1) \quad (23)$$

for the case where the government chose an interest rate defense and did not devalue in period one, with analogous expressions for the other cases.

### 7.6 *The dynamics of a speculative attack*

Government and speculator optimal behavior in the two periods, combined with a derivation of how speculators' beliefs are updated, completes the specification of the Perfect Bayesian equilibrium. It may be summarized by considering the dynamics of speculation and defense. Given their priors, speculators choose a level of speculation against the currency in period one, where a low enough prior of devaluation will mean no speculative attack. Given the level of speculation, the central bank will choose whether and how to defend as a function of its type  $(x, R_1)$ , that is, of its commitment to maintaining

the fixed rate and of its level of reserves giving it the ability to do so, as well as of the cost of the various policies, that is, the  $\ell^j$ . Suppose the government chooses, for example, an interest rate defense against the speculative attack. With some probability the fixed exchange rate collapses nonetheless. If it does not, speculators update their probability of a devaluation in the next period due to their updating their beliefs about  $x$  and  $R$ . An interest rate defense leads speculators to increase their expectation of  $x$  but to reduce their estimate of the reserves the central bank has available for a defense. If this latter effect dominates, speculators may increase the probability they assign to a devaluation in period two, thus leading to *increased* speculation against the currency.

This framework could easily be extended to more than two periods, with speculators and the central bank choosing their actions in each period as a function of their beliefs and the history of speculation and defense. The actions will evolve as a function of the evolution of beliefs about the government's commitment and ability to defend, as well as the evolution of fundamentals, in this case reserves. The framework is meant to be quite general, but the application here stresses the negative signal that may be sent by a high-interest-rate defense. It is meant to suggest why a high-interest-rate defense may be unsuccessful.

## 8 High interest rates as a positive signal

The result that high interest rates are a negative signal of the central bank's ability to defend the exchange rate depends crucially on the information structure. To further examine the signaling content of high interest rates, in this section we present an alternative specification in which the high-interest-rate defense is a positive rather than a negative signal of the central bank's ability to defend the fixed rate. Key to this result is a difference in which fundamentals are unobserved. Specifically, we suppose that rather than reserves, it is the government's fiscal position which is not fully observed. A high interest rate is then an indicator of a stronger fiscal position and hence a greater ability to withstand the costs of high interest rates.

### 8.1 *A fiscal model*

To make this more specific we use the fiscal model presented in Appendix 1, where "fiscal position" refers to the level of government domestic debt  $B$ . Otherwise, we study the same basic framework as in the previous section, but where the reserve position is observed while the level of domestic debt is not observed. As above, the degree of commitment  $x$  is not observed, and there is a stochastic shock that may force a devaluation, unknown  $ex$

*ante* to both government and speculators, where the magnitude of this shock depends on the level of government debt, with a higher level of government debt (a worse fiscal position) means that the government is more likely to be forced to devalue. Hence, a central bank's "type" as of the beginning of period one is  $(x, B)$ , where speculators have a prior distribution  $\Phi(B)$  over the level of domestic debt a government has. We assume that debt is rolled over, so that the level of domestic debt is the same in both periods. For simplicity, it is also assumed that all government types hold the same level of reserves. We solve for a signaling equilibrium in which the interest rate defense is a signal of low debt in period one, which in turn makes devaluation less likely in period two.

The sequencing of actions is the same as in the previous section, as is the set of possible policy actions. We solve the model backward from period two, leading to a Perfect Bayesian Equilibrium. Since the method of solution is the same as in the previous section, we present somewhat less detail.

## 8.2 Period two

We begin with the decision of a government of type  $(x, B)$  of how to defend. Once again we compare the expected loss from high-interest-rates and the expected loss from the borrowing defense. The difference in the expected loss is

$$\begin{aligned} \ell^H(i^H B - \tau) &- [q_2 \ell^{ZU}(i^o B + ((1 + \delta)(1 + r^z) - 1)Z - \tau) \\ &+ (1 - q_2) \ell^{ZS}(i^o B + r^z Z - \tau)] \end{aligned} \quad (24)$$

Setting this equation equal to zero defines a critical level of  $B$ , call it  $\hat{B}$ , such that if  $B \leq \hat{B}$ , the expected loss from the borrowing defense exceeds the loss from the interest rate defense, so that the interest rate defense is chosen, while if  $B > \hat{B}$ , the ranking of expected loss from the two policies is reversed, so that the borrowing defense is chosen. Intuitively, a high level of debt makes an interest rate defense quite costly, so that the use of high interest rates to defend is a signal of low debt, that is, of a stronger fiscal situation.<sup>24</sup> Note, incidentally, that  $q$  is independent of  $B$ .

Now, consider the choice of whether or not to defend the exchange rate. The structure of the argument is different than in the previous model, relying on the convexity of the loss function  $\ell$ . Consider first the case in which the

<sup>24</sup>Given the convexity of the loss function  $\ell$ , the same type of result would hold if it were able to raise revenues, that is,  $\tau$ , rather than  $B$  that was unobserved. A government with a stronger fiscal position, as represented by a high  $\tau$ , would use an interest rate defense, while one with a low  $\tau$  would use a borrowing defense. High  $\tau$  would also make the government more likely to defend, which would imply the type of signaling equilibrium derived in the text.



high-interest-rate defense is used. The critical value of  $x$  is defined by

$$\hat{x}_2^H = \frac{\ell^H(i^H B - \tau) - \ell^N(i^o B - \tau)}{1 - q_2}. \quad (25)$$

The convexity of  $\ell$  implies that the difference  $\ell^H - \ell^N$  rises as  $B$  rises, causing  $\hat{x}_2^H$  to rise. This means that more commitment types would choose not to defend. Hence, the higher is  $B$  the more likely it is that the fixed rate will not be defended. Intuitively, a higher level of debt raises the cost of defense relative to no defense, making defense less likely.

In the case in which the borrowing defense is used, the analogue to (25) is

$$\hat{x}_2^Z = \frac{q_2 \ell^{ZU}(\cdot) + (1 - q_2) \ell^{ZS}(\cdot) - \ell^N(\cdot)}{1 - q_2}, \quad (26)$$

where the arguments of  $q_2 \ell^{ZU}(\cdot) + (1 - q_2) \ell^{ZS}(\cdot)$  are defined as in (24). As in the previous case, the convexity of  $\ell$  implies that the difference  $[q \ell^{ZU} + (1 - q_2) \ell^{ZS}] - \ell^N$  is increasing in  $B$ , so that  $\hat{x}_2^Z$  is increasing in  $B$  as well. Hence, no matter which defense is chosen, a higher level of debt means a lower probability that the exchange rate will be defended in the second period.

The decision problem of the representative speculator is identical to what was derived above, namely, to choose a level of speculation as a function of the interest rate he faces and the probability of a devaluation, where this probability depends on the distribution over types conditional on first-period policy actions. The only difference is in the information set on which  $p_2$  is formed, as indicated above. Updating is represented by an equation analogous to (17).

### 8.3 Period one

The period one problem is analogous to that of the previous model, where our interest is in deriving the effect of the period one policy on expectations of a devaluation in period two, but now showing that an interest rate defense in period one is a signal of low debt, that is, a good fiscal position, and hence *decreases* the probability that speculators assign to a devaluation in the second period. We concentrate simply on the question of how to defend.

The government chooses how to defend the exchange rate in the first period to minimize expected loss over both periods. The difference in the expected loss is as in (20), repeated here for convenience:

$$\begin{aligned} \Lambda^H(\cdot) - \Lambda^Z(\cdot) = & [\ell^H - (q_1 \ell^{ZU} + (1 - q_1) \ell^{ZS}) \\ & + \beta(1 - q_1)(E \ell_2(j_1 = H)) - E \ell_2(j_1 = Z)]. \end{aligned} \quad (20)$$

As before, expected second-period loss is affected by first-period policy because of its effect on speculators's estimate of  $p_2$  which affects speculative

demand in the second period, where the estimate of  $p_2$  depends on expectations about  $B$ . The signaling effect may be summarized in the following proposition.

**Proposition 2:** If there is uncertainty about the fiscal position, a high-interest-rate defense in the first period implies a lower expected second-period loss due to positive signal about the fiscal position, implying a lower value of  $p_2$ . That is,  $El_2(j_1 = H) < El_2(j_1 = Z)$ .

Proof in Appendix 2.

The proof has the same structure as in the previous case. Intuitively, a low level of debt in the first period by itself implies use of the interest rate defense for the same reason as in the second period. Since debt levels are correlated across periods, assuming that the signal is of the opposite sign, that is,  $El_2(j_1 = H) > El_2(j_1 = Z)$ , leads to a contradiction.

## 9 Conclusions

In this paper, I have set out a number of issues that are important in understanding the choice between use of borrowing versus high interest rates to defend a fixed exchange rate against speculative attack. The primary focus was on why a high-interest-rate defense may fail even if it raises the cost of speculation and hence temporarily deters speculation. The key argument was that high interest rates may serve as a signal that a government thinks a devaluation is likely, since this implies unwillingness to take the short foreign-currency position that large borrowing implies. Furthermore, if the fiscal position is an important fundamental, high interest rates may increase the probability of devaluation if the fiscal position is known, but decrease it if there is uncertainty about the fiscal position.

On the basis of this discussion, a model was built to serve as a tool of analysis, with the time spent on model construction dictated by the absence of an existing model. The model was quite stylized in the attempt to model a number of important issues but at the same time retain tractability and derive a signaling equilibrium. The framework presented could be extended in a number of directions, including more periods, more flexibility in choice of interest rates, the possibility of both borrowing and raising interest rates to defend, etc. Though stylized, the framework should be useful in modeling a large number of currency crisis experiences. Moreover, it should provide guidance in understanding the mixed empirical results about the effect of the interest rate defense. The next step is to see whether differences in the success of an interest rate defense can be explained by differences in information structures about fundamentals.

## Appendix 1 A Fiscal Model

To justify the loss functions given in (4), we present a model of the fiscal cost of high interest rates. The government provides a public good at the end of each period which is financed by taxes  $\tau$  net of debt service, as expressed in terms of domestic currency. At the beginning of the period the government has outstanding domestic currency debt  $B_t$ , carried over from the previous period, and may issue new debt  $B_{t+1}$ . For simplicity, foreign borrowing is done only to defend the exchange rate and is paid back fully at the end of the period. Denoting the end of the period spot exchange rate by  $e_t$ , which equals 1 if there is no devaluation and  $1 + \delta$  if there is a devaluation, government expenditures in a period may be written

$$g_t = \tau + B_{t+1} - (1 + i_t)B_t - (e_t(1 + r_t^Z) - 1)Z_t \quad (A1)$$

where  $i_t = \{i^H, i^o\}$  and where  $r_t^Z$  is the interest rate at which the government borrows reserves, which may or may not be equal to  $r_t$ . We assume that if the central bank chooses to defend via high interest rates, these rates must be paid whether or not it is forced to devalue as a result of an adverse  $\omega$  shock. Hence, given  $B_t, r_t^Z$ , and  $\tau$ , an interest rate defense implies the same fiscal position whether or not there is a devaluation (remember  $Z = 0$  under the interest rate defense), while the borrowing defense implies lower public good supply if there is a devaluation than if the fixed rate is maintained.

Government expenditures provide beginning-of-period utility  $U(g_t)$ , where  $U(\cdot)$  is an increasing, concave function. Defining a loss function as  $\ell(-g) \equiv U(g)$ , we may then write the fiscal component of the current-period social loss from a policy as

$$\ell((1 + i_t)B_t + (e_t(1 + r_t^Z) - 1)Z_t - \tau - B_{t+1}) \quad (A2)$$

where  $\ell(\cdot)$  is an increasing convex function.

Our assumptions about the menu of policy options means that for any values of  $B_t, B_{t+1}, r_t^Z$ , and  $\tau$ , current-period  $\ell$  can take on four possible values, corresponding to: devaluation at the beginning of the period, that is, no defense; interest rate defense (with or without devaluation); successful borrowing defense ( $\omega_t \leq R_t + Z - D(i^o)$ ); and unsuccessful borrowing defense ( $\omega_t > R_t + Z - D(i^o)$ ). We denote these as  $\ell^N, \ell^H, \ell^{ZS}, \ell^{ZU}$  respectively and they are given by

$$\begin{aligned} \ell^N(\cdot) &= \ell((1 + i^o)B_t - \tau - B_{t+1}), \\ \ell^H(\cdot) &= \ell((1 + i^H)B_t - \tau - B_{t+1}), \\ \ell^{ZS}(\cdot) &= \ell((1 + i^o)B_t + r^Z Z - \tau - B_{t+1}), \\ \ell^{ZU}(\cdot) &= \ell((1 + i^o)B_t + [(1 + \delta)(1 + r^Z) - 1]Z - \tau - B_{t+1}). \end{aligned} \quad (A3)$$

**Appendix 2**  
**Proofs of Propositions**

**Proof of Proposition 1:** *High-interest-rate defense in the first period leads to a higher expected loss in the second period due to negative signal about available reserves, implying a higher value of  $p_2$ . That is,  $El_2(j_1 = H) > El_2(j_1 = Z)$ .*

The proof is by contradiction. Suppose that contrary to the proposition, a defense via high interest rates in the first period implies a lower expected second-period loss, that is,  $El_2(j_1 = H) \leq El_2(j_1 = Z)$ . Let  $K \equiv El_2(j_1 = H) - El_2(j_1 = Z)$ , so the contrary assumption is that  $K \leq 0$ . Equating  $\Lambda^H$  and  $\Lambda^Z$ , the critical value of  $q_1$  (see (20)) is given by

$$\hat{q}_1(\cdot) = \frac{\ell^H - \ell^{ZS} + \beta K}{\ell^{ZU} - \ell^{ZS} + \beta K}. \quad (A4)$$

There are two cases to consider. If  $-\beta K < \ell^H - \ell^{ZS}$ , then  $\hat{q}_1(\cdot)$  is interior, so that there exists a critical value of reserves  $\hat{R}_1$  such that  $R_1 < \hat{R}_1$  implies that the optimal first-period policy is  $H$ , and  $R_1 \geq \hat{R}_1$  implies that the optimal first-period policy is  $Z$ . In words, even with the positive signal sent by the interest rate defense, high enough reserve types choose  $Z$ , so that  $H$  in the first period signals lower reserves. Since,  $R_2 = R_1 - D_1(i^H) - \omega = R_1 - D_1(i^Z) + Z - \omega$ , then  $\Psi(R_2|j_1 = H) < \Psi(R_2|j_1 = Z) \rightarrow p_2(j_1 = H) > p_2(j_1 = Z) \rightarrow D_2(j_1 = H) > D_2(j_1 = Z) \rightarrow El_2(j_1 = H) > El_2(j_1 = Z)$ , a contradiction.

If  $-\beta K \geq \ell^H - \ell^{ZS}$ , then  $\hat{q}_1(\cdot) = 0$ . All reserve types therefore policy  $H$  in the first period, because of the positive signal it sends (the high value of  $-K$ ). But then  $p_2$  is independent of first-period policy, so that there is on signal a contradiction. Therefore,  $El_2(j_1 = H) > El_2(j_1 = Z)$ . This completes the proof.

**Proof of Proposition 2:** *If there is uncertainty about the fiscal position, a high-interest-rate defense in the first period implies a lower expected second-period loss due to positive signal about the fiscal position, implying a lower value of  $p_2$ . That is,  $El_2(j_1 = H) < El_2(j_1 = Z)$ .*

The proof by contradiction has the same structure as in the previous case. Suppose that contrary to the proposition, a defense via high interest rates in the first period implies that  $El_2(j_1 = H) \geq El_2(j_1 = Z)$ . Let  $K \equiv El_2(j_1 = H) - El_2(j_1 = Z)$ , so the contrary assumption is that  $K \geq 0$ . Consider first the simple case where  $K = 0$ . Then  $\Lambda^H(\cdot) - \Lambda^Z(\cdot)$  is identical to the differ-

ence in the second-period loss given in (31), so that  $\Lambda^H(\cdot) = \Lambda^Z(\cdot)$  defines the identical critical level of  $\hat{B}$ , such that if  $B \leq \hat{B}$ , policy  $H$  is chosen in the first period, while if  $B > \hat{B}$ , policy  $Z$  is chosen. Since debt levels are correlated across periods, policy  $H$  in the first period indicates that second-period debt is lower than if  $Z$  had been observed. Since the probability of no defense in the second period is increasing in second-period debt, as given by (26), one has  $p_2(j_1 = H) < p_2(j_1 = Z)$  which implies  $D_2(j_1 = H) < D_2(j_1 = Z) \rightarrow E\ell_2(j_1 = H) < E\ell_2(j_1 = Z)$ , a contradiction.

When  $K > 0$ , the difference in expected utility over the two periods may be written

$$\begin{aligned} \Lambda^H(\cdot) - \Lambda^Z(\cdot) = & [\ell^H(i^H B - \tau) + \beta(1 - q_1)K \\ & - [q_1 \ell^{ZU}(i^U B + ((1 + \delta)(1 + r^Z) - 1)Z - \tau) \\ & + (1 - q_1) \ell^{ZS}(i^S B + r^Z Z - \tau)] \end{aligned} \quad (A5)$$

As in the previous proof, one may consider two cases. When  $K$  is not too positive, then  $\Lambda^H(\cdot) - \Lambda^Z(\cdot) < 0$  for small  $B$  and  $\Lambda^H(\cdot) - \Lambda^Z(\cdot) > 0$  for large  $B$ , so the same sort of critical value argument applies as in the previous paragraph, implying a contradiction. For  $K$  to be sufficiently large (such a value need not exist),  $\Lambda^H(\cdot) - \Lambda^Z(\cdot) > 0$  for all  $B$ , so that all types would choose  $Z$ , implying no signal, which means that  $K = 0$ , once again a contradiction. This completes the proof.

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