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WORKING PAPER NO. 95-24
Informational Events That Trigger
Currency Attacks

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Abstract

When a currency is susceptible to a self-fulfilling speculative attack, some informational events will trigger an attack on the currency while others will not. We address some of the mechanisms behind this difference. We show that a large piece of bad news need not lead to an attack, provided investors agree on how to interpret that news. On the other hand, an apparently insignificant piece of news may trigger an attack if investors do not agree on how to interpret the news. The key to this difference is the operation of higher order beliefs. Uncertainty about the beliefs of others depends on subtle features of the information structure, and even small disparities in interpretation lead to large changes in the equilibrium outcome.

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My own feeling is that we do not so much need a model of the self-fulfilling crisis, but rather a model of the self-validating non-crisis, to explain why the market is willing to go along with supporting a rate that later comes under pressure without any change in the fundamentals, as certainly happened during the ERM crisis. The reason surely is that no individual asset-holder sees any benefit in shifting out of a currency just because he thinks it is overvalued; it makes sense to join the bandwagon only when one believes it has started to roll (or, for the cautious, that it is about to roll). I have to leave it to others to decide whether one can build any interesting modelling on this proposition. (Williamson (1994), pp. 19-20).

1. Introduction

Current understanding of currency crises rests on a dichotomy. In this dichotomy, currency attacks are driven either by weak fundamentals or by self-fulfilling beliefs in the presence of multiple equilibria. Fundamentals driven models (such as those of Krugman (1979) and Flood and Garber (1984a)) consider simple macroeconomic models with a unique equilibrium, where the government policies are unsustainable in the long run. The question boils down the *timing* of the collapse if a collapse is bound to occur.

Models with self-fulfilling beliefs (Flood and Garber (1984b) and Obstfeld (1986), among others) examine situations with multiple equilibria. Because the behavior of the monetary authorities will alter following an attack on the currency, an attack on an otherwise sustainable exchange rate can be self-fulfilling. A number of recent currency crises have refocused attention on the self-fulfilling beliefs scenario. The turmoil in the Exchange Rate Mechanism (ERM) of the European Monetary System in 1992 occurred in a system where it had been widely believed that political forces would sustain existing parities, and in which there had been no recent change in the fundamentals (Eichengreen and Wyplosz (1993)). In Mexico following the December 1994 crisis, U.S. policy was explicitly based on the premise that the attack outcome was just one possible equilibrium outcome (Summers (1995)).

Unfortunately, as Williamson points out in the opening quote above, the self-fulfilling beliefs scenario raises as many questions as it answers. By most accounts, both the ERM and the Mexican peso were "ripe" for attack for a long time before

the crises that brought them down - at least two years in Europe and perhaps a year in Mexico (Dornbusch and Werner (1994)). That is, at any point in those periods, concerted selling by investors would have raised the costs of maintaining the exchange rate policy sufficiently high that the abandonment of the policies would have been forced on the monetary authorities. Once they were abandoned even temporarily, governments would not have had the incentives to restore the pre-crisis parities. Thus attacks would have created profits. Why did the attacks not happen sooner? In a world of multiple equilibria and self-fulfilling attacks, what explains the *onset* of currency crises?

We will address these issues in a model in which the monetary authority is itself an interested party in an interaction with investors. We suppose that maintaining a fixed exchange rate produces some benefit to the government, either through the often cited beneficial disciplinary impact on inflation or simply because of political reputations at stake. The account in our model is couched in terms of the United Kingdom's experience in the 1992 ERM crisis. In our account, the sustainability of the exchange rate target depends on, among other things, some underlying fundamentals of the economy. If the economy is in a sufficiently favorable state, the target exchange rate can be maintained without cost *even if* all investors sell their stocks of currency. In this case, we say that the exchange rate is *stable*. On the other hand, if the economy is in a sufficiently bad state, the cost of sustaining the policy exceeds the benefit *even if* investors support the currency. In this case, we say that the exchange rate is *unstable*. However, we will be most interested in an intermediate case. Suppose that in the absence of an attack by investors, the government is prepared to incur the costs of defending the currency; but if enough investors sell, the cost of intervention is too large for the government to bear. Then we say that the currency in question is *ripe for attack*.

One reasonable premise is that both the ERM and the Mexican peso were ripe for attack and had been for some time. The story with multiple equilibria is, of course, consistent with this premise, but provides no explanation of why the attacks occurred when they did. In other words, the simple multiple equilibrium account provides no explanation of the *onset* of the currency attack. When individuals have common knowledge concerning the fundamentals, an explanation of the onset of currency attacks must appeal to *ad hoc* shifts in the equilibrium and the attendant equilibrium expectations. This is clearly unsatisfactory, unless there is an account of why expectations underwent such a shift and how individuals managed to coordinate such a shift.

We believe that a more promising line of inquiry is to consider what happens in the model if the state of the economy is no longer common knowledge. By analyzing the effect of alternative information structures on equilibrium, we may hope to identify what kind of informational events lead to currency attacks.

First, it should be noted that imperfect information, by itself, does not help us in explaining the onset of a crisis. If all investors observe a public signal concerning the true state of the fundamentals, then even though this signal may not give an accurate snapshot of the fundamentals, it is nevertheless the case that the content of the signal is common knowledge, and the description of the environment is thereby commonly known. In such situations, nothing much can be said beyond the existence of multiple equilibria.

Things become more interesting when there is differential information among the market participants, but the nature of the differences in information turns out to be crucial. An uninteresting case of differential information would be: each investor observes the true state of the economy with high probability; but with some small probability observes an incorrect signal, where the errors are independent across investors. In this case, as with the public signal, there is a multiplicity of equilibria, and no new insights are gained. In this sense, the existence of multiple equilibria is robust to various departures from perfect information. In particular, the fundamentals of the economy may deteriorate without precipitating an attack as long as the exchange rate is widely believed not to be unstable.

However, as we shall demonstrate, the situation is highly sensitive to the exact nature of the differential information. Suppose that each investor observes the true state of the economy with some noise. In particular, suppose that, conditional on the true state, the realizations of investors' signals are independently and uniformly distributed within ε of the true state. When differential information takes this form, and when transactions costs are small, it can be shown that the target exchange rate must now collapse not only in the case in which it is unstable but also if it is ripe for attack. Among other things, this implies that the multiplicity of equilibria disappears, and holding on to the currency is no longer an equilibrium action. Thus, an equilibrium argument provides an explanation of the onset of a currency attack.

What explains the difference between the two differential information structures? Why does an arbitrarily small amount of differential information have no effect in one case but guarantee an attack in the other? Qualitatively, the difference is that in the first case there was a high probability that investors got exactly

the same information and interpreted it in the same way. In the second case, the investors got almost (but not exactly) the same information with probability one. Thus there is uncertainty about how to interpret the information. *It is uncertainty about how to interpret information that leads to a currency attack.* As a case in point, much ink has been spilt since the 1992 ERM crisis concerning the support (or the lack thereof) offered by the Bundesbank. The fact that commentators still disagree on this issue is an indication that disparities of interpretation still exist. As we argue below, even small (and apparently insignificant) differences in information can generate large shifts in the equilibrium response.

The paper is organized as follows. In section 2, we present the basic framework. In section 3 we analyze the impact of differential information and provide a formal description of the mechanism driving the onset of a currency attack as sketched above. The proofs of the main results are contained in section 4. Sections 5 and 6 contain discussions of the results and their implications.

2. The Model

2.1. The Framework

Our model is concerned with the interactions between the U.K. government and a group of speculators who operate in the foreign exchange market. The backdrop for their actions is a competitive sector in the foreign exchange market whose net demand for sterling can be written as

$$D(e, \theta). \tag{2.1}$$

Here, e denotes the deutschmark/sterling exchange rate (i.e., the number of deutschmarks that can be obtained for one pound sterling), so that a high e represents a 'strong pound' in common parlance. We do not model explicitly the portfolio decisions of individuals in the competitive sector, but simply assume that the net demand for sterling is strictly decreasing in e . The net demand for sterling also depends on θ , where θ represents some underlying fundamental 'state of the economy' for the U.K. such that the net demand for sterling is strictly increasing in θ .

It may be convenient to view θ as the level of domestic output in the U.K., so that a high θ is associated with a high transactions demand for sterling. However, our arguments in this paper do not presuppose any particular account of the

macroeconomy, and alternative interpretations may be borne in mind, provided that the net demand for sterling is increasing in θ and decreasing in e . We will assume that θ may take any value between 0 and 1, and that the actual value of θ is drawn from a uniform distribution on the unit interval $[0, 1]$. Against this backdrop, we introduce a continuum of risk-neutral *arbitrageurs*, each of whom is small relative to the total population. The arbitrageurs start out by holding sterling balances. We normalize the total sterling balances of the arbitrageurs to be 1, and denote by s the aggregate sale of sterling by them.

In the absence of government intervention, the floating exchange rate is determined by market clearing in which any sale of sterling by the arbitrageurs is met by a positive net demand by the competitive sector. We will denote by

$$f(\theta, s) \tag{2.2}$$

the exchange rate e at which the net demand $D(e, \theta)$ of the competitive sector is matched by the sale s of sterling by the arbitrageurs. In other words, $f(\theta, s)$ is the value of e that sets $D(e, \theta) = s$. Since net demand for sterling is increasing in θ , the floating rate $f(\theta, s)$ is increasing in θ and decreasing in s .

We now turn to the motivation of the U.K. government. Suppose that the government has an exchange rate target of e^* . Maintaining this target exchange rate has a per-period value of $v > 0$ to the U.K. government, perhaps because of its anti-inflationary impact, or more simply, because of the political reputations at stake. However, intervention in the foreign exchange market is costly for the government. We will suppose that the cost to the government of intervening in the market by buying x pounds sterling is $c(x)$. For instance, the government may have to borrow reserves, possibly at premium interest rates, in order to intervene in the market. Along more Keynesian lines, the cost of intervention could also be interpreted as the cost of higher U.K. interest rates (necessary to defend the target exchange rate) on domestic output and income. For simplicity, it will be assumed that intervention to rectify a positive net *demand* for sterling is without cost. In this case, we assume that the government can simply accumulate foreign reserves.

Thus, the function $c(\cdot)$ is such that $c(x) = 0$ if $x \leq 0$ and that $c(x)$ is positive and strictly increasing in x when x is positive. To avoid trivialities, we assume that if the size of intervention is large, the cost exceeds the value v of maintaining the target. In particular, if the state of the economy θ is at its minimum ($\theta = 0$), the net supply of sterling by the competitive sector alone is too large for the

government to intervene willingly in support of the target rate e^* . That is,

$$c(-D(e^*, 0)) > v. \quad (2.3)$$

We define three regions for the value of θ . First, let θ^* be the value of θ such that $c(-D(e^*, \theta) + 1) = v$. The quantity $-D(e^*, \theta) + 1$ is the net supply of sterling at the state θ when all the arbitrageurs sell their holdings of sterling. Thus, when the state of the economy is θ^* , even if all the arbitrageurs sell their sterling balances, the government is indifferent between intervening to maintain the target rate e^* and allowing sterling to depreciate.

Next, define θ_* to be the value of θ which solves $c(-D(e^*, \theta)) = v$. That is, θ_* is the value of θ at which, even if all the arbitrageurs *hold on* to their sterling balances, the government is indifferent between intervening to maintain the exchange rate at e^* and allowing sterling to depreciate. When the value of θ lies below θ_* , the government strictly prefers not to intervene. Since the cost of intervention is increasing in the size of the net supply of sterling, we have $0 < \theta_* < \theta^* < 1$. Thus we can identify three possible regions for the value of θ (see figure 1).

- We say that θ lies in the *stable* region if $\theta \in [\theta^*, 1]$. In this case, the exchange rate target will be maintained, since the cost of government intervention is outweighed by the payoff v . In this region, the actions of the arbitrageurs cannot influence the government's choice, since even if they were to sell their entire sterling balances, the cost of intervention is less than the benefit v .
- We say that θ lies in the *unstable* region if $\theta \in [0, \theta_*]$. In this case, while it may be possible (physically) for the government to maintain the target rate, the cost outweighs the benefit, and it will choose not to intervene. This is the case irrespective of the actions of the arbitrageurs, since the net supply of the competitive sector is already too large for the government to intervene willingly.
- Finally, we say that θ lies in the *ripe for attack* region if $\theta \in (\theta_*, \theta^*)$. In this case, the government's decision on intervention depends on the actions of the arbitrageurs. If all the arbitrageurs sell their holding of sterling, the floating exchange rate is not compatible with the target rate, and the government will allow a depreciation. However, if all the arbitrageurs hold on to their sterling balances, the benefit to the government of maintaining

the exchange rate at e^* exceeds the cost. In this case, the government will choose to maintain the exchange rate of e^* .

As we develop the model, this tripartite distinction will remain crucial. For any value of θ in the ripe for attack region, the government prefers to maintain the target rate of e^* provided that no more than some fraction $\alpha(\theta)$ of arbitrageurs sell their sterling balances. We will call $\alpha(\theta)$ the *trigger mass* at the state θ . As the terminology suggests, the fraction $\alpha(\theta)$ represents the proportion of arbitrageurs who need to sell their sterling holdings in order to precipitate a depreciation of sterling. Since the net demand of the competitive sector is increasing in θ , the trigger mass $\alpha(\theta)$ is increasing in θ , $\alpha(\theta_*) = 0$, and $\alpha(\theta^*) = 1$.

We will impose a condition on the floating rate $f(\theta, s)$ to the effect that, if the government is forced into a devaluation when θ is *low*, the extent of the devaluation is larger than if the devaluation takes place when θ is high. In other words, when the fundamentals are weak, any forced devaluation results in a lower exchange rate than when the fundamentals are strong. Formally, we can express this condition by saying that the function

$$f(\theta, \alpha(\theta)) \tag{2.4}$$

is (weakly) increasing in θ .

The motivation behind an arbitrageur's decision can be understood in the context of this model. Because an arbitrageur is small relative to the population and is risk-neutral, it is without loss of generality to consider the arbitrageur's choice to be binary — that is, to sell one's sterling holdings or to hold on to it. The decision to sell sterling incurs a per unit cost of $t > 0$ for an individual arbitrageur. This cost may be interpreted either as a standard transactions cost, or as a tax on transfers of capital if such a tax were to exist.

The payoff of an arbitrageur to holding sterling depends on whether the government maintains the target rate e^* or whether sterling is allowed to depreciate to find its floating rate. If the government maintains the exchange rate at e^* , an arbitrageur's payoff to holding sterling is normalized to zero. If the government does *not* defend the exchange rate so that sterling is allowed to find its floating rate f , the payoff to holding sterling is given by

$$f - e^*, \tag{2.5}$$

the difference between the floating rate f and the target rate e^* . The payoff of an arbitrageur to selling his holding of sterling is given by the constant

$$-t, \tag{2.6}$$

and does not depend on the value of θ . Thus, the act of selling sterling guarantees a fixed payoff at all states of the economy.

2.2. A Benchmark Case

If the government and all the arbitrageurs are able to observe the realization of the state of the economy θ perfectly, we can characterize the situation in terms of the following extensive form game of perfect information.

- Nature chooses the true state of the economy θ in accordance with the uniform distribution.
- The arbitrageurs and the government observe the value of θ perfectly. Each arbitrageur then decides whether to continue to hold sterling. This determines s , the aggregate sale of sterling by the arbitrageurs.
- The government, having observed s and θ , decides whether to defend the target rate of e^* . When the government has made its decision, the exchange rate is determined, and the participants (the government as well as the arbitrageurs) receive their payoffs as described above.

The analysis of the case when all participants have perfect information concerning θ constitutes a benchmark for our main discussion below. The outcome in equilibrium falls under three cases, depending on the value of θ . If θ lies in the stable region, the target rate e^* is maintained irrespective of the actions of the arbitrageurs. Hence, for an individual arbitrageur, it is a dominant action to hold on to one's sterling balances. In contrast, if θ lies in the unstable region, then the floating rate will be below the target rate, irrespective of the actions of the arbitrageurs. Hence, it is a dominant action for an arbitrageur to sell his sterling balances. The interesting case is when θ lies in the ripe for attack region. Here, the equilibrium exchange rate depends on the actions of the arbitrageurs. If all of them were to sell, the government prefers to allow a depreciation, and the resulting payoff to holding sterling is negative. If all of them hold on to their sterling balances, the government prefers to defend the target rate.

Given the anticipated response of the government to their actions, the arbitrageurs face a coordination game. If all of them could be relied on to hold on to sterling balances, a depreciation can be averted. Thus, one equilibrium in the ripe for attack region is for all arbitrageurs to hold on to sterling. However, from the point of view of an individual arbitrageur, if all others sell their sterling holdings (thereby precipitating a depreciation), and if the transactions cost t is small, it is in his interest to sell his own sterling balances. Thus, the ripe for attack region gives rise to multiple equilibria when the arbitrageurs observe θ perfectly. We will now see how the analysis may change when they have imperfect and differential information.

3. Imperfect and Differential Information

Before introducing our main analysis, it is useful to discuss two alternative situations in which imperfect information does *not* introduce any qualitative departures from the benchmark case of perfect information. They are cases of ‘innocuous’ departures from perfect information, and we label them as ‘symmetric imperfect information’ and ‘well-behaved differential information,’ respectively. They will serve to accentuate the impact of our main framework.

3.1. Symmetric Imperfect Information

Instead of observing the true state of the economy, suppose that all arbitrageurs observed a public signal whose realization is distributed within ε of the true state i.e., in the interval $[\theta - \varepsilon, \theta + \varepsilon]$. Denote the common message as m . Now their decision to sell will be a function of the message m , not the true state. However, the fact that the message is public implies that the content of the message is common knowledge. Indeed, if $m \in [\theta_* + \varepsilon, \theta^* - \varepsilon]$, then it is common knowledge that θ is in the ripe for attack region, and multiple equilibria will continue to exist. Qualitatively, the analysis is identical to the benchmark case with perfect information.

3.2. Well-Behaved Differential Information

Now suppose that each arbitrageur observes one of two signals. The first signal reveals the true state without error, and each arbitrageur has access to this signal with probability p . However, with probability $1 - p$, an arbitrageur observes a

signal that is completely uninformative, whose realization is drawn uniformly from the interval $[0, 1]$, independent of the state. Moreover, the probability of observing one signal as opposed to another is independent of the type of signal observed by the others.

This scenario is intended to depict a state of affairs where each arbitrageur may have access to good information or to no information at all. However, when p is close to 1 there is again no qualitative change in the conclusions from that with perfect information. Each arbitrageur's decision to sell is now a function of the (individual) message he receives. But for any θ in the ripe for attack zone, there will be a p sufficiently close to 1 such that there is an equilibrium where no one attacks if they observe message θ . The reason is that, as long as t is strictly positive, whenever all other arbitrageurs hold on to their sterling balances, it is a *strict* best response for an arbitrageur to hold on to sterling himself. Thus, provided that p is large enough, the strategy in which an arbitrageur holds on to sterling for every realization of the signal in the ripe for attack zone is a symmetric equilibrium strategy.

Thus far, the departure from perfect information does not introduce any qualitative departures from the benchmark case. However, we now turn to our main framework in which the differential information brings about a fundamental shift in the character of the outcome. We call this the case of 'noisy differential information.'

3.3. Noisy Differential Information

Suppose that the arbitrageurs obtain independent information concerning θ , but with a small degree of possible error. In particular, assume that if the true state of the economy is θ , an arbitrageur observes a message m that lies in the interval $[\theta - \varepsilon, \theta + \varepsilon]$, where ε is a small positive number. (In particular, $\varepsilon < \min\{\theta_*, 1 - \theta^*\}$). Moreover, we suppose that the distribution of the possible messages received by an arbitrageur conditional on θ is uniform on the interval $[\theta - \varepsilon, \theta + \varepsilon]$, and that messages (conditional on θ) are independent across arbitrageurs.

The game is as before, except that now arbitrageurs' decisions are made contingent on their signals. For simplicity, let us focus on a simple class of equilibria. A *k-trigger strategy* is a rule of action for an arbitrageur in which, if the message received is below k , the arbitrageur sells his holding of sterling, while if the

message received is at or above k , he holds on to his sterling balances. We will examine the properties of symmetric equilibria in trigger strategies, that is, equilibria in which all arbitrageurs employ identical trigger strategies. A symmetric equilibrium in which all arbitrageurs employ the k -trigger strategy is dubbed a *k-trigger equilibrium*. Two properties of trigger equilibria may be summarized by the following pair of results.

Theorem 1. *For any $k \in (\theta_* + \varepsilon, \theta^* - \varepsilon)$, there is a unique tax rate $t > 0$ such that the k -trigger strategy is a symmetric equilibrium strategy.*

Theorem 2. *For any message $m \in (\theta_* + \varepsilon, \theta^* - \varepsilon)$, there is a number $t_0 > 0$ such that, if the tax rate t is lower than t_0 , then in every trigger equilibrium, all arbitrageurs sell their sterling holdings given message m .*

The first result may be interpreted in the following way. The interval $(\theta_* + \varepsilon, \theta^* - \varepsilon)$ is of some significance in our model since, if an arbitrageur receives a message in this interval, he knows that his message differs from the true state θ by at most ε , so that he knows that the true θ lies in the ripe for attack region (θ_*, θ^*) . Thus, theorem 1 states that, for any message k that informs an arbitrageur that the true state is in the ripe for attack region, there is an appropriate tax rate (which is unique, given k) for which this message is the trigger point in a trigger strategy equilibrium. In short, any trigger strategy in this class can be supported by the appropriate tax regime.

The second result depicts a state of affairs that is a significant departure from the case with perfect information. With perfect information concerning θ , any point in the ripe for attack region gives rise to a strict equilibrium in which all arbitrageurs hold on to their sterling balances. Theorem 2 states that when there is noisy differential information, and an arbitrageur knows that the true θ is in the ripe for attack region, if the tax rate is low, the only action in equilibrium is to sell. Thus, even though an arbitrageur knows that θ is consistent with the target exchange rate, it is not possible to hold on to sterling as an equilibrium action. Arbitrageurs are compelled to sell by equilibrium logic.

The formal argument for these results are gathered in the next section. However, before plunging into the formal argument, it is worth pausing to think about these results. Why did the noise have such a large impact? The key to our result is that, with noise, no matter how small ε is, it is never common knowledge that the exchange rate is sustainable. Suppose that you observe a signal m_i which is

much greater than θ_* . For small ε , you know that the true value of θ is much greater than θ_* , and you know that all the other arbitrageurs know this too. But it is not common knowledge. Let us show why.

When do you know that $\theta \geq \theta_*$? If you observe a signal greater than $\theta_* + \varepsilon$. When do you know that everyone knows that $\theta \geq \theta_*$? Equivalently, when do you know that everyone has observed a signal greater than $\theta_* + \varepsilon$? Since others' signals can differ from yours by at most 2ε , this will be true if you observe a signal greater than $\theta_* + 3\varepsilon$. This argument is clearly one that will iterate to ensure that there is " n th order knowledge" that $\theta \geq \theta_*$ (i.e., everyone knows that everyone knows... (n times) that everyone knows it) exactly if everyone has observed a signal greater than or equal to $\theta_* + (2n - 1)\varepsilon$. But there is common knowledge that $\theta \geq \theta_*$ if and only if there is n th order knowledge for every n (that is the definition). Thus, it is never common knowledge that θ is not in the unstable region.

To see why a failure of common knowledge may be important, it is instructive to contrast the role of uncertainty in strategic situations from that in single person decision problems. In a single person decision problem, payoffs are determined by one's action and the state of the world. When a decision maker receives a message that rules out some states, this information can be used directly by disregarding these states in one's deliberations. However, the same is not true in strategic situations in which the payoff of an agent depends on the actions of other agents, as well as the state of the world. Since my payoff depends on your actions and your actions are motivated by your beliefs, I care about the range of possible beliefs you may hold. So, when I receive a message that rules out some states of the world, it may not be possible to disregard these states in my deliberations, since some of these states may carry information concerning your beliefs. Furthermore, your beliefs at these neighboring states may depend on your beliefs concerning my beliefs at a further set of states. The reasoning does not stop here. Unless there is some feature of the situation that curtails this sequence of iterated beliefs, higher order beliefs of all orders will be relevant for my decision now. Thus, in contrast to the single person decision problem, I may be forced to take into consideration states that are known not to have occurred. In short, even though everyone knows that an exchange rate parity is sustainable, they are forced into taking into consideration what they would have done if the parity is unsustainable.

For simple 2×2 games or for two player finite action games, game theorists have explored this theme in some detail (see Monderer and Samet (1989), Carlsson

and van Damme (1993) and Morris, Rob and Shin (1995)). For such games, it has been established that, without common knowledge of payoffs, there will be a tendency for the “safer” equilibrium to be played. That is, players choose an action that gives a reasonable payoff even if other players do not play according to equilibrium. In our more complex game, something of the same flavor comes through. Selling sterling could be seen as a safer act in the sense that the payoff is less sensitive to what others do. Holding on to sterling may yield higher payoffs if everyone can coordinate their actions, but it is a riskier act in the sense that the higher payoff is obtainable only if coordination is achieved.

With these preliminaries, we proceed to prove our two theorems.

4. The Argument

In proving our pair of results, we need some preliminary groundwork. Let us first outline the consequences of all arbitrageurs using a trigger strategy. If arbitrageurs use the k -trigger strategy, the aggregate sale of sterling by them will depend on how many of them have received a message that is below k . If the true θ is below $k - \varepsilon$, then all arbitrageurs will have received a message that is below k , and hence will sell sterling. Similarly, if the true θ is above $k + \varepsilon$, the aggregate sale of sterling is zero, since all arbitrageurs will have received a message above k . In general, if we denote by

$$s(\theta, k) \tag{4.1}$$

the aggregate sale by the arbitrageurs at the state θ when they employ the k -trigger strategy, $s(\theta, k)$ is given by

$$s(\theta, k) = \begin{cases} 0 & \text{if } \theta \geq k + \varepsilon \\ 1 & \text{if } \theta \leq k - \varepsilon \\ \frac{k + \varepsilon - \theta}{2\varepsilon} & \text{if } k - \varepsilon < \theta < k + \varepsilon \end{cases} \tag{4.2}$$

Figure 2 illustrates $s(\theta, k)$ as the shaded area under the density function to the left of k . By substituting the function $s(\theta, k)$ into the expression for the floating exchange rate $f(\theta, s)$, we obtain an expression for the floating exchange rate at state θ when the arbitrageurs use the k -trigger strategy. For a given k , this floating rate is a function of θ and is given by $f(\theta, s(\theta, k))$. Figure 3 illustrates this function as the bold line that straddles the functions $f(\theta, 1)$ and $f(\theta, 0)$.

[Figure 3 here]

Since the floating exchange rate is increasing in θ and decreasing in the sale of sterling by the arbitrageurs, while $s(\theta, k)$ is decreasing in θ , the function $f(\theta, s(\theta, k))$ is increasing in θ .

Although f gives the exchange rate that would rule in the absence of government intervention, the actual payoffs for the arbitrageurs will be determined after the government has decided whether to intervene. Thus, when arbitrageurs decide on their optimal action, they anticipate how likely it is that the government will intervene. The government defends the target rate e^* unless the cost of intervention exceeds v . Recall the definition of the *trigger mass* $\alpha(\theta)$ at the state θ . The trigger mass is the proportion of arbitrageurs who must sell in order to induce the government to cease intervention and allow sterling to find its floating rate. When θ lies in the ripe for attack region, we know that $\alpha(\theta)$ is strictly between 0 and 1. For any k in the interval $(\theta_* + \varepsilon, \theta^* - \varepsilon)$ we will associate a number

$$d(k), \tag{4.3}$$

which denotes the state θ at which the government is just indifferent between intervening to maintain the target rate and letting the currency float given that the arbitrageurs are using the k -trigger strategy. Geometrically, $d(k)$ is the state at which the area under the density function (centered on $d(k)$) to the left of the trigger point k is given by the trigger mass at this state. We will call $d(k)$ the *devaluation point* given trigger strategy k . Figure 4 illustrates the devaluation point for k . When θ is to the left of $d(k)$, the exchange rate at the end of the game is the floating rate f . When θ is to the right of $d(k)$, the target rate e^* is maintained. We shall refer to this function as the *post-intervention exchange rate* given the trigger point k , and denote it by $\psi(\theta, k)$. Figure 5 illustrates $\psi(\theta, k)$. The post-intervention exchange rate determines the payoff function to the act of holding sterling for a given trigger point k . At state θ , the payoff to holding sterling is given by $\psi(\theta, k) - e^*$, the difference between the post-intervention exchange rate and the target rate e^* .

With these preliminaries, we are now ready to prove our pair of theorems. Let us first prove theorem 1. Suppose that $k \in (\theta^* + \varepsilon, \theta^* - \varepsilon)$, and that all arbitrageurs except one (called i) is following the k -trigger strategy. Suppose that arbitrageur i has received the message k' , and let us consider the conditional expected payoff of holding sterling given message k' when all other arbitrageurs follow the k -trigger strategy. We denote this expected payoff by $\Pi(k', k)$. Since the prior density over the state θ is uniform and the message conditional on θ is also uniform, arbitrageur

i 's conditional density over the states θ given the message k' is also uniform, with support $[k' - \varepsilon, k' + \varepsilon]$. Thus, the conditional expected payoff to holding sterling given message k' when all other arbitrageurs follow the k -trigger strategy is given by

$$\Pi(k', k) = \frac{1}{2\varepsilon} \int_{k'-\varepsilon}^{k'+\varepsilon} (\psi(\theta, k) - e^*) d\theta. \quad (4.4)$$

Since $\psi(\theta, k)$ is weakly increasing in θ , so is the expected payoff given message k' . Also, when k lies in the interval $(\theta_* + \varepsilon, \theta^* - \varepsilon)$, we have the following preliminary results.

Lemma 1. *If $k \in (\theta_* + \varepsilon, \theta^* - \varepsilon)$, then $k - \varepsilon < d(k) < k + \varepsilon$.*

Proof. The devaluation point $d(k)$ is the value of θ that satisfies

$$\theta = k + \varepsilon(1 - 2\alpha(\theta)), \quad (4.5)$$

where $\alpha(\theta)$ is the trigger mass at θ . Since $k \in (\theta_* + \varepsilon, \theta^* - \varepsilon)$, this value of θ lies in the ripe for attack region, so that the trigger mass is strictly between zero and 1. Hence, $\theta > k + \varepsilon$ and $\theta < k - \varepsilon$, so that the result follows.

Lemma 2. *In the interval $(\theta_* + \varepsilon, \theta^* - \varepsilon)$, $d(k)$ is invertible and strictly increasing in k , but $d(k) - k$ is strictly decreasing in k .*

Proof. Since $d(k)$ is the value of θ such that $\theta = k + \varepsilon(1 - 2\alpha(\theta))$, k is given by $\theta - \varepsilon(1 - 2\alpha(\theta))$. Since α is a function of θ , so is k . To show that $d(k)$ is increasing in k , it suffices to show that its inverse is increasing in θ in the interval (θ_*, θ^*) . This follows from the fact that $k = \theta - \varepsilon(1 - 2\alpha(\theta))$, and α is strictly increasing in θ . Finally, note that $d(k) - k = \varepsilon(1 - 2\alpha(d^{-1}(k)))$, which is decreasing in k , since both α and d^{-1} are increasing functions.

Now, consider $\Pi(k, k)$. This is the expected payoff to holding sterling conditional on message k when all arbitrageurs are using the k -trigger strategy. Since $\psi(\theta, k) = e^*$ for all $\theta \geq d(k)$, we have:

$$\Pi(k, k) = \frac{1}{2\varepsilon} \int_{k-\varepsilon}^{k+\varepsilon} (\psi(\theta, k) - e^*) d\theta = \frac{1}{2\varepsilon} \int_{k-\varepsilon}^{d(k)} (f(\theta, s(\theta, k)) - e^*) d\theta < 0, \quad (4.6)$$

where the second equality follows from the fact that the intervention rate is equal to the floating rate below the devaluation point. The inequality follows from lemma 1 and the fact that $\psi(\theta, k) - e^* < 0$ for $\theta < d(k)$. Thus, if we choose the tax rate $t = -\Pi(k, k)$, any arbitrageur who receives the marginal message k will be indifferent between holding sterling and selling it. Moreover, since $\Pi(k', k)$ is increasing in the message k' , any arbitrageur who receives a message higher than k will prefer to hold sterling, while if the arbitrageur receives a message lower than k , he prefers to sell sterling. In other words, if the tax rate t is defined as above, then the k -trigger strategy is a best reply to the use of the same strategy by all other arbitrageurs. In short, the k -trigger strategy is a symmetric equilibrium strategy. This proves theorem 1.

To prove theorem 2, we start by noting that when $\theta = d(k)$, we have $s(\theta, k) = \alpha(\theta)$. Also, since $s(\theta, k)$ is decreasing in θ , while $\alpha(\theta)$ is increasing in θ , we have $s(\theta, k) \geq \alpha(\theta)$ if $\theta \leq d(k)$. Thus, we have the following inequality for any value of θ at or below $d(k)$.

$$f(\theta, s(\theta, k)) \leq f(\theta, \alpha(\theta)). \quad (4.7)$$

Now, choose a point $m \in (\theta_* + \varepsilon, \theta^* - \varepsilon)$, and consider the expected payoff $\Pi(k, k)$, where $k \leq m$. We then have the following sequence of inequalities:

$$\begin{aligned} \Pi(k, k) &= \frac{1}{2\varepsilon} \int_{k-\varepsilon}^{d(k)} (f(\theta, s(\theta, k)) - e^*) d\theta \\ &\leq \frac{1}{2\varepsilon} \int_{k-\varepsilon}^{d(k)} (f(\theta, \alpha(\theta)) - e^*) d\theta \\ &\leq \frac{1}{2\varepsilon} \int_{m-\varepsilon}^{d(m)} (f(\theta, \alpha(\theta)) - e^*) d\theta \\ &< 0 \end{aligned}$$

The first inequality follows from the fact that $f(\theta, s(\theta, k))$ is bounded above by $f(\theta, \alpha(\theta))$ in the range of the integral, while the second inequality follows from the fact that $f(\theta, \alpha(\theta))$ is a non-decreasing function of θ and $d(m) - m \leq d(k) - k$, by lemma 2. The last integral is strictly negative due to lemma 1 and the fact that $f(\theta, \alpha(\theta)) < e^*$ for θ in the ripe for attack region. Now, choose the number

t_0 so that

$$t_0 = -\frac{1}{2\varepsilon} \int_{m-\varepsilon}^{d(m)} (f(\theta, 0) - e^*) d\theta. \quad (4.8)$$

If the tax rate is strictly below this number, we have $\Pi(k, k) < -t$. Moreover, this is the case for every $k \leq m$, so that there is no trigger equilibrium whose switching point lies to the left of m . Thus, if there is a trigger strategy that is a symmetric equilibrium strategy given tax rate t , every arbitrageur sells sterling at every point to the left of m . This is the statement of theorem 2.

5. Discussion

Our main results can be summarized as follows. If the economy is in the ripe for attack zone, and there is perfect, symmetric or even well-behaved differential information, there will be multiple equilibria: attack and no attack. However, if transactions costs are low and there is noisy differential information, then an attack must take place, even in the ripe for attack zone. Let us emphasize the key features of the model driving our result. First, there exists an intermediate zone (the ripe for attack zone) where the exchange rate regime is stable only so long as arbitrageurs do not co-ordinate an attack. Second, in this zone the attack equilibrium is "safer" in the sense that it is optimal to attack even if you attach only a small probability to others' attacking. Finally, the information structure is such that even when the target exchange rate is consistent with the fundamentals, (and known to be so), it is never common knowledge that it is stable. Each of these features is sensitive to government policy, and we will follow up some of the implications for policy in the concluding section. In this section, we shall discuss some of the modelling issues that arise from our analysis in an effort to distinguish our contribution from other, superficially similar arguments, and to point to some limitations of our model that need to be addressed in future work.

Formally, we have studied an essentially static model of arbitrageurs' behaviour - their decisions were simultaneous - and analyzed the implications of alternative information structures. The comparative statics are those of changing information structures. Clearly, it would be more convincing if we could give an explicitly dynamic story. In particular, two essentially dynamic components of currency attacks could profitably be incorporated into the analysis.

First, there is the existing literature considering the timing of fundamentals-driven speculative attack. Krugman (1979), building on earlier work of Salant and Henderson (1978), showed how an apparently speculative attack could be driven by fundamentals. Suppose the government has a fixed supply of foreign reserves with which to defend the exchange rate, and that the exchange rate the government is trying to defend is not sustainable, in the sense that the supply of domestic currency at that exchange rate exceeds demand. Then the exchange rate will eventually collapse. But if the collapse did not occur until the government actually ran out of reserves, there would be huge potential profits for speculators: buying dollars immediately before the collapse would earn huge profits. Therefore the collapse must occur before the government actually runs out of reserves. For reasons that will typically not be apparent to an outside observer, there will be a date at which speculators will suddenly purchase the balance of the foreign exchange reserves and the exchange rate will collapse. This elegant idea underlies much analysis of the timing and nature of speculative attacks in recent years. The basic idea has been extended to stochastic models. It remains a challenge for future work to examine the interaction between this type of timing issue and the differential information issues raised in this paper.

Second, there is the question of information transmission through the market. In a dynamic market, arbitrageurs may be able to learn through time the information of others. Indeed, this phenomenon suggests a related but theoretically quite distinct explanation for currency attacks. Banerjee (1992) and Bikhchandani, Hirshleifer, and Welch (1992) have considered the phenomenon of information cascades. Translated into this environment, such an argument would go as follows. Suppose that the question of whether the exchange rate collapses is *exogenous* to the behavior of a group of arbitrageurs. Thus, among other things, the payoff arising from my action does not depend on the actions chosen by the other arbitrageurs. Each arbitrageur has some information about the likelihood of collapse. Arbitrageurs decide - sequentially and publicly - whether to sell their holdings of sterling. Now, if the first N arbitrageurs happen to have received bad signals and sell, the $(N + 1)$ th arbitrageur may choose to ignore his own information - even if it is positive - and sell, based on the revealed information of those who came before him. But once arbitrageurs start ignoring their own information, no information can reverse the unlucky first few signals.

Let us first note that the superficial resemblance between our own *infection argument* and the cascade argument is quite spurious. The infection argument op-

erates only when the underlying payoffs describe an inherently strategic situation where my own payoffs depend on the actions of others. Indeed, that is the only reason that higher order beliefs could possibly matter. The cascades argument, by contrast, relies on actual observations of others' actions. The absence of common knowledge plays no essential role.

This is not to deny that there may be some element of cascades in currency attacks. The fact that I observe your selling does convey some information and may push me into selling. However, there are two reasons to think that a pure cascades story may not be the driving force behind currency attacks. First, as Lee (1993) has emphasized, the cascade argument relies on a discrete action space so that individuals completely ignore their own information. But as was the case in our model, traders can vary their strategies continuously, and so can adjust their strategies to new information. In contrast, cascades depend on the fact that the action space is sufficiently coarse that information revelation is precluded. Second, and perhaps more important, cascade arguments are ill-suited in situations where genuine strategic interactions take place, in the sense that payoffs depend non-trivially on the actions of others. A fully fledged dynamic extension of the analysis presented in this paper would be one that combines the infection argument and the cascade argument. This topic seems worthy of further investigation.

6. Implications for Policy

One interpretation we may put on the case of 'noisy' differential information is that the recipients of the differential information learn of the true underlying fundamentals of the economy with little error, but that there are small discrepancies in how these messages are interpreted by the recipients. In extrapolating our theoretical analysis to the analysis of policy, we would like to propose that in looking for a cause or a trigger for a currency attack, we should look for the arrival of noisy information, i.e., news events not interpreted in exactly the same way by different arbitrageurs. The informational events that matter are quite subtle. A "grain of doubt," allowing that others may believe that the economy is, in fact, unstable, will lead to a currency crisis even if everyone knows that the economy is not unstable. In predicting when crises will occur, average opinion or even extreme opinion need not precipitate a crisis. Rather, what matters is the higher order beliefs of some participants who are apprehensive about the beliefs of others, concerning the beliefs of yet further individuals, on these extreme opinions.

This seems broadly consistent with at least some interpretations of recent currency crises. Before the European Monetary System crises of 1992, exchange rates may have been misaligned. But if anything, the situation had improved over the previous two years (Eichengreen and Wyplosz (1993)). Before the Mexican crisis of December 1994, the underlying imbalances had been observable for at least a year (Dornbusch and Werner (1994)). In each case, many stories can be told about fundamentals, but there is little evidence that the timing had much to do with any secular deterioration.

Instead, we should look for extreme beliefs that "infected the market." In Mexico, rumors of political trouble in Chiapas province were widely cited (New York Times (1994)). Presumably, few investors believed that events in Chiapas were actually going to influence the fundamentals of the Mexican economy. But it was enough that they believed that others might believe that others might.

In Europe, pronouncements that the Bundesbank would no longer support some of the currencies outside the core of the EMS were apparently important. What effect did these have on each individual's beliefs about how the Bundesbank would behave? Probably not much - the Bundesbank's lukewarm support was well known. Much more important may be uncertainty about how others would interpret the new announcements. Indeed, the very fact that commentators are still arguing about the content of the Bundesbank's announcements only supports this view. It is not enough to know the truth. One has to worry about whether others know it as well and about whether others know that others know it.

If it is the case that currency crises may be precipitated by higher order beliefs, even though participants believe that the fundamentals are sound, then the policy instruments that will stabilize the situation need not be draconian. For instance, consider the proposal by Eichengreen, Tobin and Wyplosz (1993) that there should be a tax on short-term capital movements. In our model, this is equivalent to increasing t , and thus altering the individual trade-offs in the stampede. In this sense, our model gives a theoretical rationale as to why a small tax might have a large impact on outcomes. Although our analysis has not conducted a welfare analysis of the issue, it is quite conceivable that if the equilibria are Pareto ranked, the small welfare loss associated with a transactions tax is more than outweighed by the welfare gain arising from selecting the Pareto superior equilibrium.

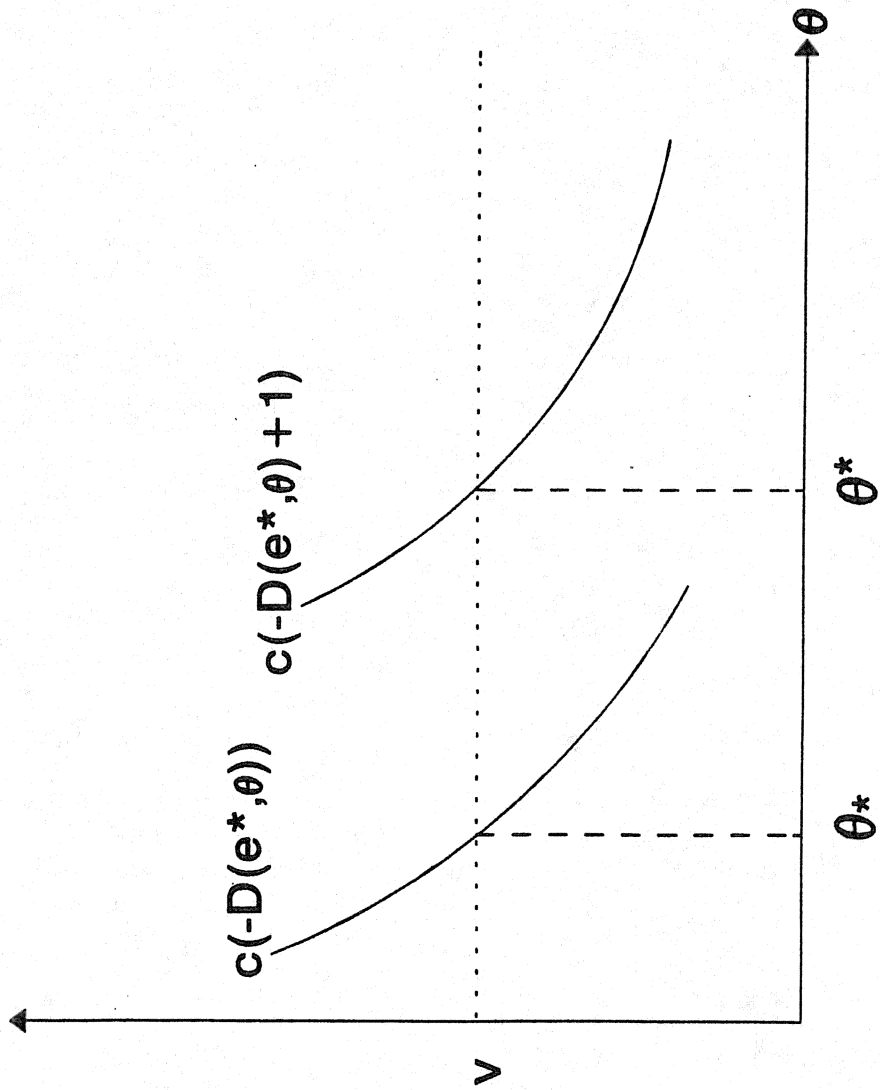
Also, a public announcement by a lender of last resort easily breaks the argument guaranteeing the attack. The Clinton administration has explicitly described the \$40 billion dollar rescue package for the Mexican peso as an attempt to deal

with multiple equilibria in fundamentals. Understanding the importance of higher order beliefs helps us understand exactly what kind of guarantees are effective.

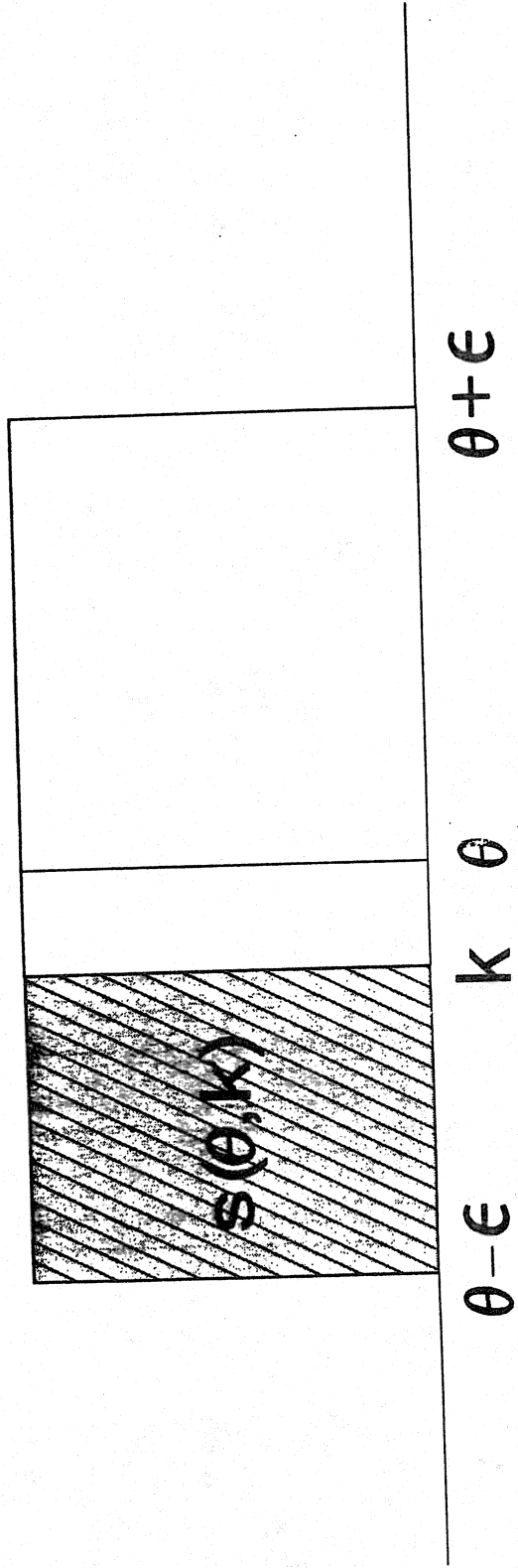
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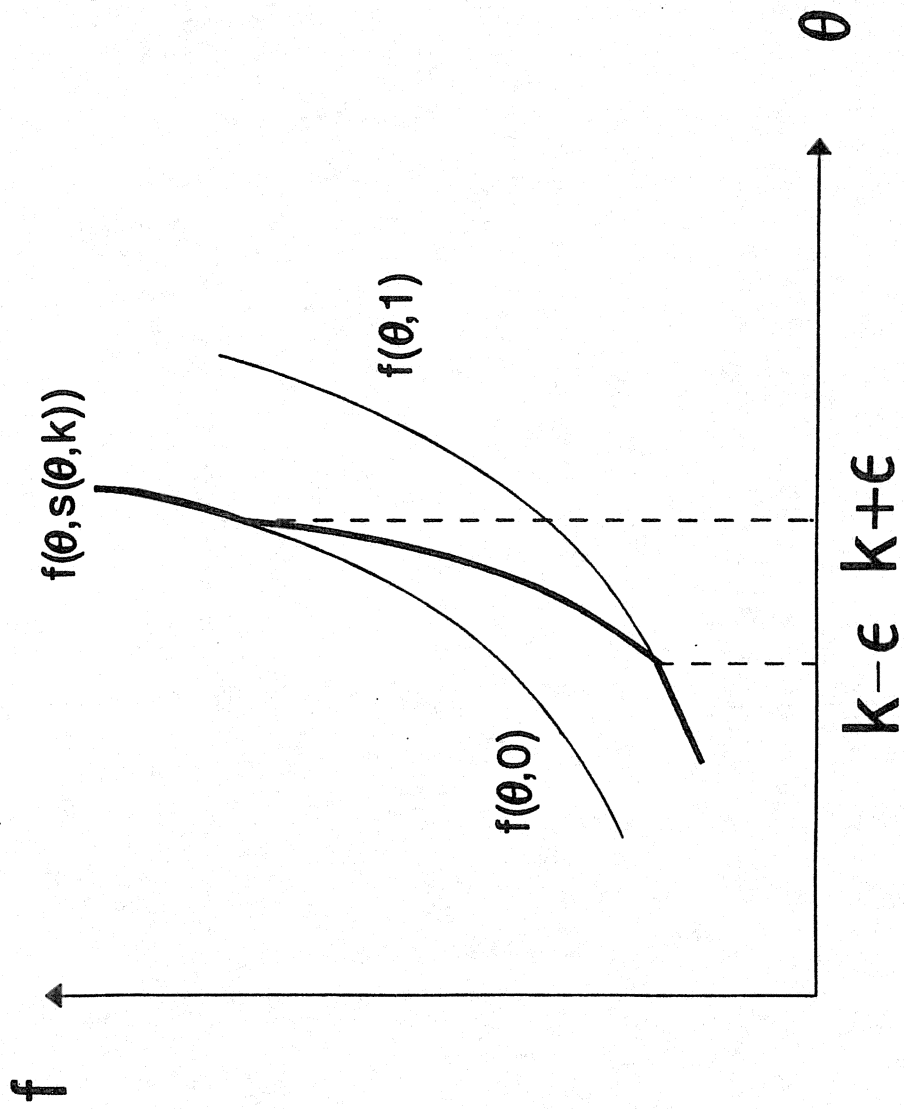
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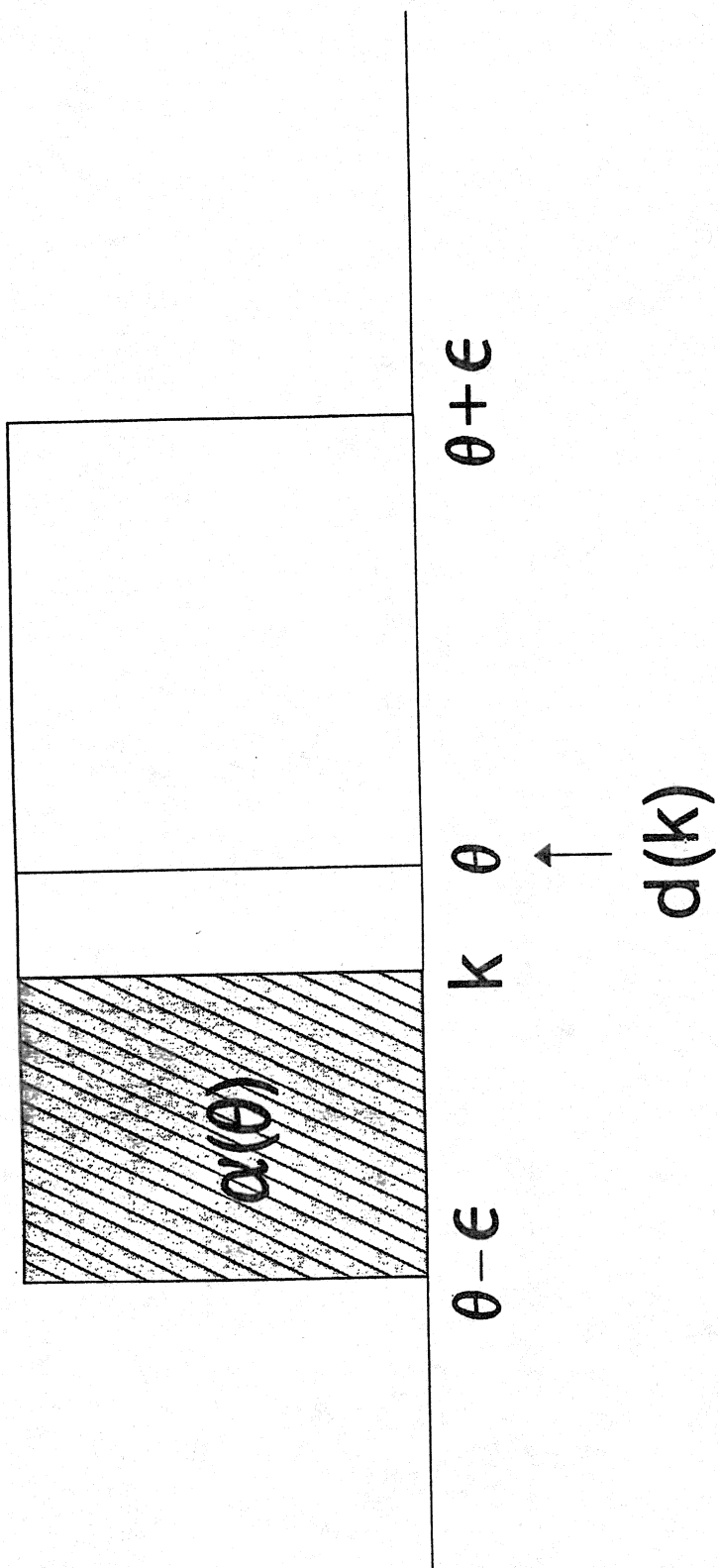
[Figure 1]



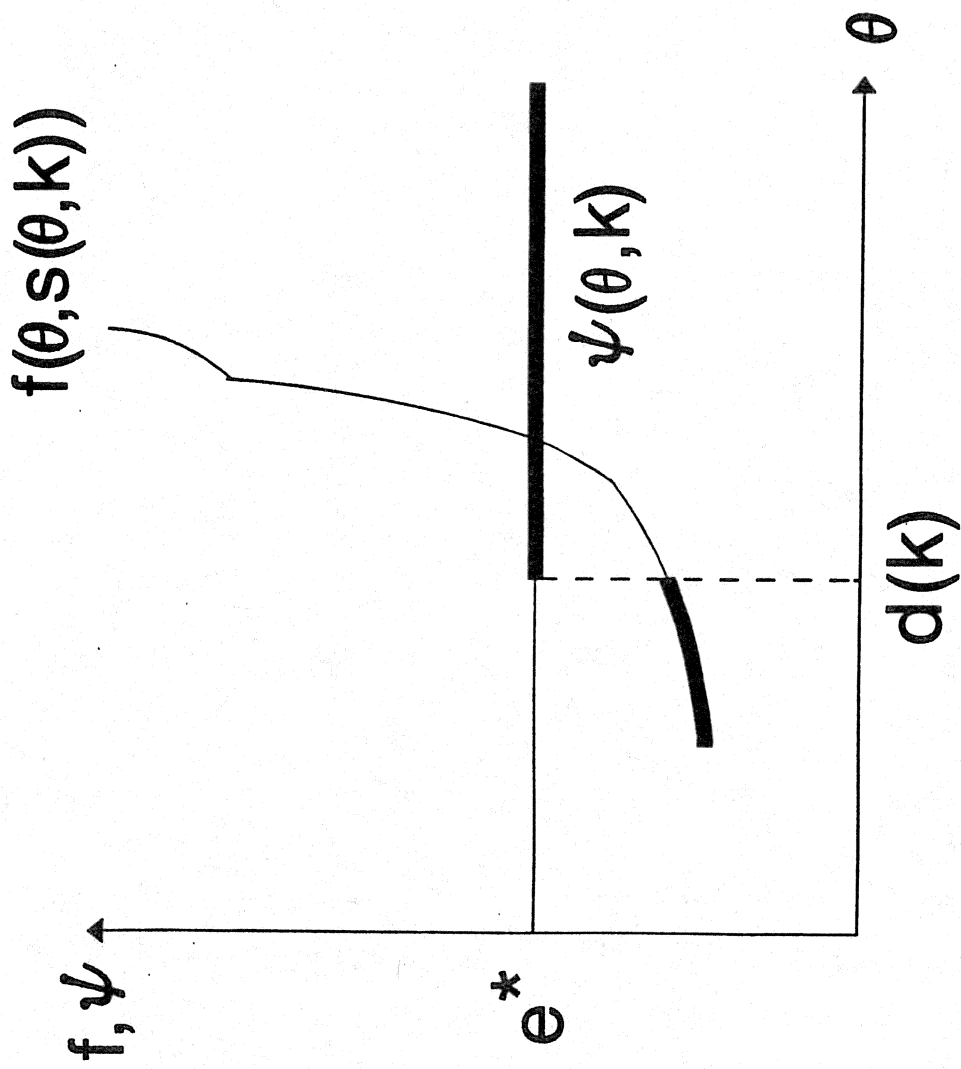
[Figure 2]



[Figure 3]



[Figure 4]



[Figure 5]

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