Pirates and Fishermen: Is Less Patrolling Always Bad?

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Abstract

Motivated by the Somali fishermen-pirates, I explore the time allocation decision of potential pirates between piracy and an alternative non-violent occupation, fishing, when the returns of both piracy and fishing are sensitive to patrolling intensity. For a range of parameters, the static model yields multiple equilibria, an "efficient" one with no patrolling and low piracy, a less efficient equilibrium with intermediate levels of both piracy and patrolling and a highly inefficient high-patrolling high-piracy equilibrium. Analyzing the dynamic analogue, I obtain the surprising result that sufficiently low patrolling can be a good strategy.

Keywords: Pirates, fishermen, patrolling, multiple equilibria, policy responses.

1. Introduction

Maritime piracy has become a burgeoning industry, one that is estimated to cost the global community between 7 and 12 billion dollars a year (Bowden 2010). In 2010, Somali pirates alone were paid an estimated 238 million dollars in ransoms.[2] In spite of the magnitude of modern high seas piracy, and the prominence of pirate-related stories in the world news, however, it has received relatively little attention from economists.

Leeson (2007a, 2009a,b,c, 2010a,b, 2011, Leeson and Rogers forthcoming) has frequently written about pirates, though his primary focus is on seventeenth and eighteenth century pirates, particularly their internal organization and governance. Anderson and Marcouiller (2005) analyzed a two-country Ricardian model where agents could choose between trade, domestic autarky production and piracy, and showed that autarky obtained over a large parameter space. In an earlier paper (Guha and Guha 2011) I examine the options available to pirates and traders on a "pirate-infested sea" i.e assuming there is always an infinitely elastic supply of pirates prepared to attack a vessel as long as it is profitable for them to do so. That paper emphasized the deterrent effects of patrolling. The current paper, however, turns the focus

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[2] Bowden (2010) : see also http://www.independent.co.uk/news/world/africa/out-of-control-piracy-set-to-cost-world-1639bn-by-2015-2269013.html and http://www.eyefortransport.com/content/maritime-piracy-costs-global-community-12-billion-year

on the "supply side" of piracy by emphasizing potential pirates' time allocation decisions between piracy and a non-violent alternative, fishing. I ask whether patrolling will deter pirates in this situation, and find surprising results.

My particular focus in this paper is motivated by the following. Most Somali pirates appear to have been fishermen who turned to piracy, or to still be part-time fishermen (Axe 2009). The reason why fishermen turned to piracy is linked to a sharp drop in returns to fishing resulting mostly from overfishing by international fishing trawlers (Ploch et al 2011), which, according to a UN report[3], catch fish worth the rough order of magnitude of a year's ransom payments from Somali waters every year.[4] Interestingly, besides depressing the returns of local fishermen, the presence of these trawlers may also directly increase the return to piracy, as they often make easy targets for pirates seeking ransom.[5] Meanwhile, while naval patrols have been stepped up in an effort to combat piracy, another motive for increased patrolling has also been to protect international fishing trawlers, as stated in a U.N Security Council Resolution (October 2008)[6], and there are reports that these trawlers also respond positively to increased security from patrols.[7] Moreover, while the increase in patrolling has increased the proportion of *unsuccessful* pirate attacks from roughly .37 in 2007 to about .75 in 2010, the *number* of pirate attacks is nonetheless increasing, at least off East Africa (111 in 2007 versus 219 in 2010)[8].

Some skeptics doubt the extent to which international fishing trawlers have harmed the local fishing industry. They point out that Somali waters are rich in many kinds of fish, so that in spite of the activity of international fishing trawlers, local fishermen's returns may not have

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[3] S/2011/30. See also a report by the Marine Resources Assessment Group on unregulated fishing off the waters of developing countries : http://www.imcsnet.org/imcs/docs/iuu_fishing_synthesis_report_mrag.pdf.
[4]Schofield (2010) puts the figure at between 90 and 300 million US dollars. See also http://articles.chicagotribune.com/2008-10-10/news/0810090770_1_somalia-ground-for-industrial-waste-pirates and http://www.independent.co.uk/opinion/commentators/johann-hari/johann-hari-you-are-being-lied-to-about-pirates-1225817.html.

[5] http://www.time.com/time/world/article/0,8599,1892376,00.html#ixzz1CSWx3AyA

[6] S/RES/1838, available at http://www.securitycouncilreport.org/site/c.glKWLeMTIsG/b.6156401/k.26A6/August_2010brSomalia_Piracy.htm#UNDocs.

[7] http://wardheernews.com/Articles_09/Jan/Waldo/08_The_two_piracies_in_Somalia.html. Moreover anti-piracy patrols sent by individual countries aim to provide safe escort to their own fishing vessels, see http://hdff.org/course/opportunities-for-collaboration/.
[8] Sources : UN Report S/2010/394, Ploch et al. (2009).

fallen much. They also point out the difficulty in assigning a monetary value to the local fishermen's loss. Since international trawlers sell their ware in different markets from the local fishermen, it is difficult to measure the extent of the pecuniary externality they impose on the local fishing industry. They also suspect that pirates may find it in their interest to drum up sympathy from western observers or media by trying to overstate the local fishing industry's losses (indirectly providing a "justification" for their acts). Historically, many pirates have engaged in such "public relations manipulation", often with successful results, as Leeson finds in his work on seventeenth and eighteenth century Caribbean pirates. Note, however, that for the purposes of my analysis the exact extent of the loss imposed on local fishing by international trawlers is not important. It does not matter whether fishing is still lucrative, it only matters that it be less lucrative than before. Moreover, even if the studies assessing the extent of damage to local fishing are flawed, if pirates believe their own propaganda, we will obtain exactly the same results as if there were a real drop in the returns to fishing.[9]

From the facts above, we see that the response to patrolling is likely to be complex. On one hand, patrolling should have a deterrent effect on piracy by reducing the probability of successful pirate attacks and increasing the probability of capture. However, the facts suggest that it may also have other impacts on incentives for piracy and on the relative attractiveness of piracy and fishing. I build a simple model exploring some of these effects.

I find that with plausible parameter restrictions, a static model yields multiple equilibria – a steady state with a low level of pirate activity and no patrolling, one with intermediate levels of both and one with a high level of piracy and patrolling. The latter seems closer to the current situation where pirate attacks remain high in spite of a rather high level of patrolling (note that this is not incompatible with pirate attacks declining in response to increased patrolling over some ranges). In a dynamic analogue of the model, the middle equilibrium is unstable, while the high piracy-high patrolling equilibrium can be stable, as is the equilibrium with no patrolling and low piracy. [Convergence to the high-patrolling high piracy stable equilibrium may involve periods of declining pirate activity]. An implication is that when patrolling is sufficiently low, it could trigger a decline in both piracy and patrolling; with pirate activity ultimately stabilizing at a positive but relatively low level despite the absence of external patrols.

[9] This is because the time allocation decision between piracy and fishing is dictated by *expected* returns. If potential pirates expect low returns from fishing, they act in exactly the same way as they would if these returns were really low and they correctly anticipated this.

My model does not of course incorporate all possible aspects of piracy in Somalia. For example, it is often pointed out that Somali piracy is partly a product of the unusual political economic situation in Somalia (analyzed in Leeson 2007b). In particular, it is often alleged that the increase in piracy is a product of the collapse of the state. Interestingly, however, fishermen-pirates in the region appear to be largely supported by the "microstates" of Puntland and Somaliland rather than from the utterly stateless southern part of Somalia. While these political economy aspects are intriguing, I abstain from modeling them to maintain focus.

In addition to the economics literature on maritime piracy already mentioned, this paper is also connected to the wider economics literature on crime. This literature began with Becker's (1968) pioneering study on the economics of crime and punishment, and includes, among many others, Stigler (1970), Schelling (1971), Anderson (1979), Reuter (1983,1987), Jennings (1984), Arlacki (1986), Jankowski (1991), Dick (1995), Konrad and Skaperdas (1998), Garoupa (2000), Skaperdas (2001), Chang, Lu and Chen (2005) and Miceli (2010). Most of these papers study the causes or effects of organized crime or optimal prevention methods. Leeson and Rogers (forthcoming) study hierarchy in criminal organizations (the mafia and pirates) and its interaction with entry barriers to criminal activity. This idea is somewhat similar to my model in that I incorporate a (psychological) barrier to engaging in violent activity. However I treat the decision as an individual one and do not model organized crime or issues of hierarchy. Other papers (like Levitt 1997 and many others surveyed in Cameron 1988) empirically investigate the effect of policing on crime. Since I analyze the effect of patrolling on piracy attempts my work is linked to this literature.

The rest of the paper is organized as follows. Section 2 contains the benchmark static model. Section 3 contains a dynamic analogue which analyzes stability. I conclude with a discussion of implications in section 4.

2. A Static Model

There is a large pool of "potential pirates" (numbering N), each with a labor endowment of 1, which can be divided between piracy and fishing. Potential pirates are alike. They like income and incur an extra cost from engaging in a violent occupation (piracy) as opposed to a non-violent one. The utility function of such an individual is given by

$$U(Y,\alpha) = u(Y) - v(\alpha) \tag{1}$$

Here, Y represents income, α is the fraction of working time spent on piracy, u is the component of utility that denotes utility from income, and v is the psychic cost of engaging in a violent occupation, which depends on α, the time spent in it (of course, Y also depends on α as will be made explicit shortly). For simplicity I assume that u and v are additively separable; one's distaste for violence is not affected by income changes. I make the standard assumptions of diminishing marginal utility of income and increasing marginal cost so that $u'>0, u''<0, v'>0, v''>0$. Now we have

$$Y = \alpha P(p) + (1-\alpha) r(p) \qquad (2).$$

Income is a function of time allocated to piracy versus fishing and the returns in the two occupations, P(p) being the return from piracy and r(p) the return from fishing ; both returns are sensitive to p, patrolling intensity. Let both functions be continuous and twice differentiable. We have

$$P = (1-p)L(p) - pS \qquad (3)$$

A patrolling intensity p results in a probability of capture p in which case the pirate is subjected to a penalty S[10]. With probability 1-p, the pirate's attack is successful and he earns a "loot" L (which may comprise ransom payments or stolen cargo). Moreover the value of the booty he can capture may itself depend on patrolling intensity, as we discuss in detail shortly.

Potential pirates take p as given, and decide on α. They maximize (1) subject to (2) and their labor endowment. The optimal time devoted to piracy, α^*, solves the first-order condition

$$[P(p) - r(p)]u'(Y(\alpha^*)) = v'(\alpha^*) \qquad (4).$$

Clearly α^* is a function of p. Moreover, it is clear that if P(p) < r(p), agents never engage in piracy as they incur a psychic cost from doing so. I focus on the more interesting range where this is not so, ie, the probability of capture p is not high enough to lower expected income from piracy below expected income from fishing, so that $\alpha^* > 0$. It also appears to be true that expected pirate incomes *are* considerably higher than expected alternative incomes – both historically and currently[11].

I now examine how α^* is likely to change with a change in patrolling intensity. First, consider the return to fishing. As argued in the introduction, one of the objectives of countries

[10] Currently S tends to be rather light as there is a fear of trying captured pirates on location in case international law is violated [Leeson 2010b, 2011].

[11] Leeson (2007a) provides figures on historical pirate incomes while a Geopolicity study (May 2011) provides figures on current pirate incomes.

stepping up patrols is to protect their own fishing vessels which fish in or near pirate hubs, and fishing vessels are likely to respond positively to increased protection. This in turn lowers local fishermen's return from fishing, so we have $r'(p) < 0$. Meanwhile, the return to *piracy* responds according to

$$P'(p) = -S - L(p) + (1-p)L'(p) \tag{5}$$

The first two terms on the RHS of (5) indicate that a rise in p reduces the expected income from piracy by making it less likely that a pirate succeeds in capturing his loot L and by making it more likely that he is caught and punished. The third term indicates the effect of greater security on the size of the loot that a pirate can capture in the event that he is successful (which happens with probability 1-p). As discussed above, international fishing vessels respond positively to greater security and could in turn make easy prey for pirates, hence we have $L'(p) > 0$, a factor which tends to reduce the negative impact of increased p on the income from piracy. However, this is a second order effect unlike the first order effects of the reduction in the pirate's probability of success. I restrict the analysis in the text to the zone where (5) is negative[12] ; this is equivalent to assuming an upper bound on the response of the size of the loot to increased security, that is, a cap on $L'(p)$. A sufficient condition for this cap to hold for all p is that the elasticity of booty L with respect to probability of a successful pirate attack 1-p be less than unity [i.e $(1-p)L'(p)/L(p) < 1$]. A weaker sufficient condition is:

A1: $L'(p) \leq S + L(0)$ for all p

Also, note that

$$P''(p) = -2L'(p) + (1-p)L''(p) < 0 \text{ if } L''(p) \leq 0. \tag{6}$$

As p rises, a pirate is less likely to succeed; hence a possible increase in booty is not as powerful a consideration. Thus the response of piracy income to p, $P'(p)$, becomes increasingly negative as p increases (when the first derivative is negative, a negative second derivative indicates that the function is falling at an *increasing* rate). A sufficient (but not necessary) condition for this is that the pirate's loot if successful should not increase at an *increasing rate* with p.

Thus when p increases, the return to fishing falls while the return to piracy also falls - at an increasing rate - with p. Now define a condition under which when there is no security, a small increase in security depresses the return to fishing more than the return to piracy:

[12] Appendix B contains an analysis of the case where (5) is positive.

$$|r'(0)| \geq S + L(0) - L'(0) = |P'(0)| \quad (7)$$

Observation 1: Consider parameters such that (6) and A1 hold. Then

(a) If $r''(p) \geq 0$, α^* can initially rise and then fall with a rise in p. Moreover,

(b) α^* always falls with p at high enough p.

(c) Condition (7) is a sufficient, but not necessary, condition for α^* to always increase with p for at least small p.

Proof: (a) If $r''(p) \geq 0$, then the return to fishing falls at a falling rate with p (note that when the first derivative of a function is negative, a positive second derivative indicates that the function is falling at a *decreasing* rate). In conjunction with (6), we therefore have

$$\frac{d}{dp}[P'(p) - r'(p)] = P''(p) - r''(p) < 0 \quad (8)$$

Totally differentiating (4) and rearranging terms, we have

$$\frac{d\alpha^*}{dp} = \frac{[P'(p) - r'(p)]u'(Y(\alpha^*)) + [P(p) - r(p)][\alpha^* P'(p) + (1-\alpha^*)r'(p)]u''(Y(\alpha^*))}{v''(\alpha^*) - [P(p) - r(p)]^2 u''(Y(\alpha^*))} \quad (9)$$

Note that the denominator of (9) is positive given $v'' > 0, u'' < 0$. Moreover given A1, we have $P'(p) < 0$; given $u'' < 0, r'(p) < 0$, therefore, the second term of the numerator is also positive. This term represents an income effect; an increase in security reduces the fisherman-pirate's expected income, raising its marginal utility and encouraging him to devote more time to piracy rather than fishing in order to boost his income. Now $\frac{d\alpha^*}{dp}$ is necessarily positive if $P'(p) - r'(p) > 0$ (in which case an increase in security reduces the return to fishing by more than it reduces the return to piracy, making piracy relatively more attractive) but becomes negative if $P'(p) - r'(p)$ becomes sufficiently negative. In conjunction with (8) we find that if $\frac{d\alpha^*}{dp}$ is positive at p*, it is also positive for p < p*; similarly, if it is negative at a (larger) value of p, p**, it is also negative for p > p**. Therefore, we see that α^* can initially rise and then fall with a rise in p.

(b) To see why α^* will always fall at high enough p, note that at p = 1, we have $P(1) = -S < r(1) \geq 0$. That is, agents will completely specialize in fishing even before p reaches 1; hence α^* will have fallen to 0 at p < 1.

(c) Condition (7) implies that piracy's attractiveness relative to fishing increases for small increases in p, starting from p = 0. Thus the first term in the numerator is also positive resulting in unambiguously positive $\frac{d\alpha^*}{dp}$ over a non-empty range of p. However, even if condition (7) does not hold, α^* will still increase with p over a non-empty range provided the return to piracy is not falling much faster than the return to fishing. In that case, the initial increase in α^* is solely attributable to the income effect. QED.

Observation 1 shows that when patrolling is low, an increase in patrolling can induce agents to spend more time on pirate activity. However, this effect is reversed when patrolling becomes high enough. Now define a variable $n = \alpha^* N$ measuring the extent of pirate activity (recalling that there are N agents). Obviously, n, like α^*, is a function of p.

Now, consider policy-makers' response to pirate activity. The microfoundations for the policy response function that I use here are developed in detail in Appendix A. The chief characteristics of this function are that policy-makers do not supply any patrolling until pirate activity reaches a threshold, after which they respond positively to an increase in pirate activity. Thus the policy response function is given by

$$p = p(n), p'(n) > 0 \text{ for } n \geq \underline{n} \tag{10}$$

$$\text{and } p(n) = 0 \text{ for } n < \underline{n} \tag{11}$$

where $\underline{n} > 0$. Moreover, assume that $\underline{n} > n(0)$, the level of pirate activity that prevails when there is no patrolling.

While the appendix contains a detailed explanation and derivation, here I very briefly outline the intuition underlying this sort of policy response. The policy-maker chooses patrolling intensity to maximize his political gains net of costs. The higher the level of pirate activity, the more politically aware citizens and media are of this problem, and the greater the policy-maker's political mileage from patrolling. This, combined with fairly standard restrictions on gain and cost functions, ensures that the optimal level of patrolling is increasing in the level of pirate activity. However, it can be shown that accounting for the policy-maker's optimization, his gains (net of costs) only become non-negative at a strictly positive level of pirate activity, which I call $\underline{n}$. Moreover, his net gains are increasing in the level of pirate activity. Hence, for all levels below this threshold, he finds it uneconomical to supply any patrolling at all, while above this threshold, his optimization exercise is no longer constrained by the requirement that net gains be non-negative, and he responds to an increase in n by raising p. I have also argued, in the appendix, that it does not matter whether all the patrolling is supplied by a single country's government, or by multiple governments individually deciding on their own patrolling levels (in the latter case, of course, aggregate patrolling p would be the sum of each country's patrolling, and we should think of the policy response function below as an aggregate response).[13] Interestingly enough some (eg Hanson, 2010) point out that piracy began to draw attention from policy-makers only in 2008 – having reached dramatic levels – even though the International Maritime Bureau's piracy statistics indicate that a positive level of piracy existed much prior to this. This is in tune with a policy response that comes forth only after pirate activity reaches a certain level.

Definition: An equilibrium comprises a doublet (n*, p*) such that given the equilibrium level of pirate activity, n*, policy-makers do not choose a different level of patrolling, and given the equilibrium level of patrolling, p*, no other level of pirate activity is chosen.

Proposition 1: Consider a policy response function described by (10) and (11). Then, subject to A1, and the sufficient condition (7), a necessary and sufficient condition for the existence of multiple equilibria is that $\exists p$ such that $\frac{1}{p'(n)} < n'(p) = N\frac{d\alpha^*}{dp}$. There are then three equilibria, one with zero patrolling and low piracy, the second with intermediate levels of both patrolling and piracy, and the third with high levels of both.

Proof: From Observation 1 (c), condition (7) is sufficient for $\frac{d\alpha^*}{dp}$ and hence $n'(p)$ to be positive for at least small p. By assumption, the policy response function $p(n)$ has a higher intercept on the n axis than the piracy function $n(p)$. Now if $\exists p$ such that $\frac{1}{p'(n)} < n'(p) = N\frac{d\alpha^*}{dp}$, then the policy response function cuts the piracy function from below. This first intersection necessarily occurs on the upward sloping part of the piracy function – hence at low levels of both n and p. Moreover, given the monotonicity of the policy response function and the fact that the piracy function eventually declines, there must be a second intersection at a higher level of both p and n. This may, but need not, be at a level of patrolling where pirate activity has commenced to decline. We can now characterize three equilibria:

[13] Please see Appendix A for further details.

(a) $(n(0), 0)$: Given that there is no patrolling, pirate activity is optimally at level $n(0)$, hence pirates have no incentive to change their level of piracy. Given that $n(0) < \underline{n}$, the policy-makers' optimal response, by (11), is to keep patrolling at zero.

(b) (n*, p*) ; this is the first intersection between $n(p)$ and $p(n)$. Again, given that both pirates and policy makers are optimizing, this is an equilibrium, one with intermediate levels of both patrolling and piracy.

(c) (n**, p**): this is the second intersection between $n(p)$ and $p(n)$. This involves high levels of both piracy and patrolling, even though piracy may, but need not, have commenced to decline in response to patrolling by this point. QED.

Figure 1: Multiple Equilibria

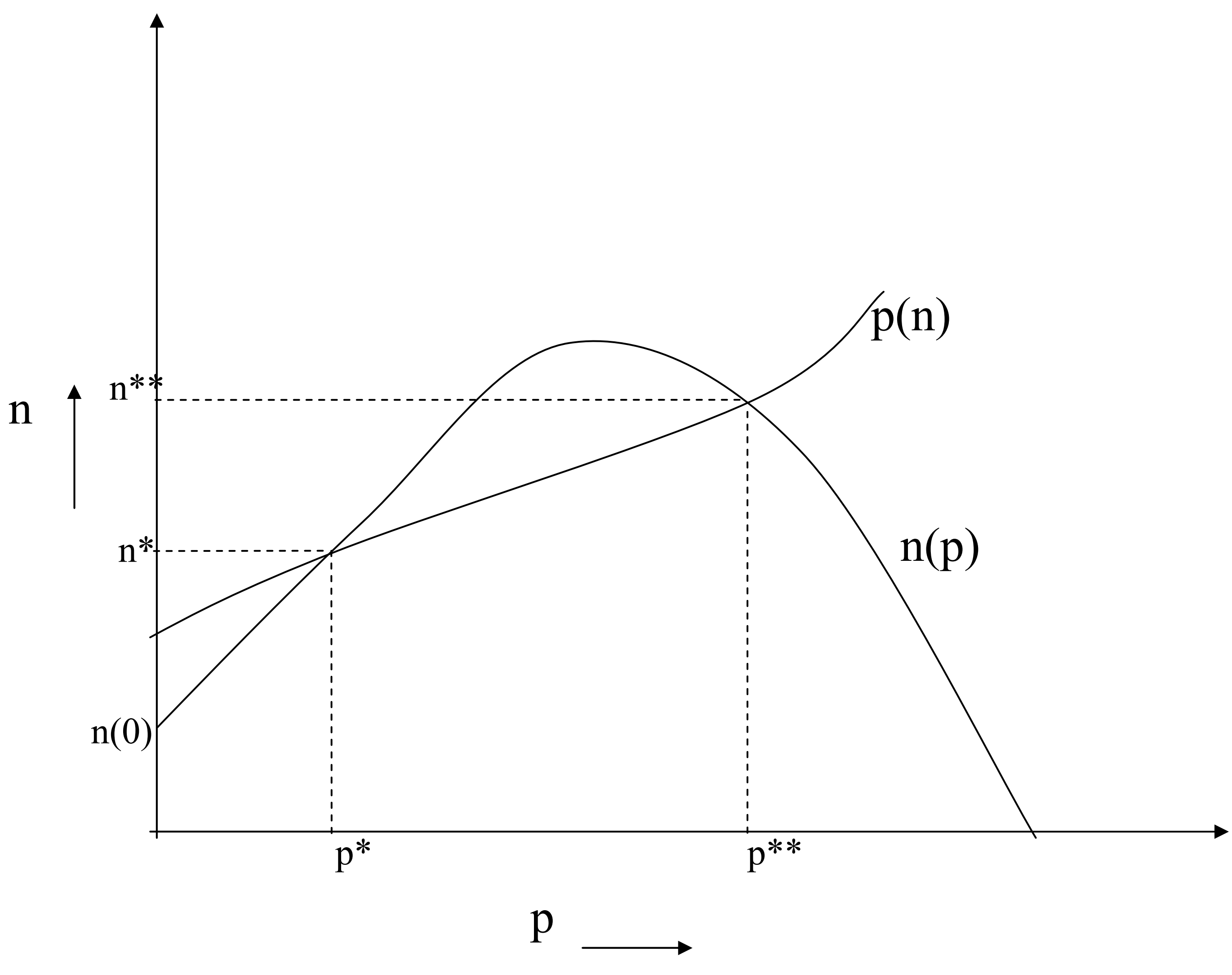

Figure 1 illustrates Proposition 1. Note that the figure captures four features[14]:

1. $n(0) > 0$: a positive level of piracy exists when patrolling is zero. This is equivalent to assuming that (4) has an interior solution at $p = 0$. This happens if the return to piracy is sufficiently higher than the return to fishing even when there are no patrols around. In this case, the marginal utility of the extra income effect from piracy outweighs individuals' marginal distaste for violence inducing them to spend a nonzero amount of time on piracy.

2. $n(p)$ is hump shaped ; the optimal level of pirate activity first increases and then falls in the level of patrolling. This essentially follows from Observation 1. Initially, an increase in patrolling depresses returns to both piracy and fishing, inducing an income effect encouraging individuals to spend more of their time on the more lucrative option, piracy. Moreover, the return to fishing is also initially falling by a greater extent than the return to piracy. Both these factors tend to make piracy go up with patrolling when patrolling is small. Eventually, however, the greater risk of capture and the lowered chances of securing a prize as a result of patrols catch up with pirates and the returns to piracy start falling faster than the returns to fishing, encouraging a movement away from piracy.

3. $p(n) = 0$ when $n < \underline{n}$. This is so because at low levels of pirate activity, the political gains to policy-makers from supplying patrolling fall short of the costs of supplying a positive level of patrolling. Hence policy makers do nothing.

4. $p(n)$ is monotonically increasing for $n \geq \underline{n}$. This follows from the policy makers' optimization exercise (details in appendix A). A driving factor is that the higher the level of pirate activity, the more the political pressure on the policy-maker to increase patrolling. Essentially, once the level of pirate activity exceeds the minimum threshold for economical intervention, fairly standard restrictions on gain and cost functions ensure that the policy-maker's optimal level of patrolling increases in the level of pirate activity.

Figure 1 shows three steady states ; a "no patrolling, low piracy" one, a "intermediate patrolling, intermediate piracy" one and a "high patrolling, high piracy" one. These steady states can be ranked in descending order of efficiency; equilibria which involve lower pirate activity also entail less patrolling, which is cost-saving. However, the system may conceivably be

[14] I will briefly talk about what happens when features 1 and 3 are violated.

trapped in the least efficient equilibrium. Here, pirate activity remains high despite high patrolling.

A possible co-ordination device guiding the system to the more efficient equilibrium may then involve announcements by policy-makers regarding resolutions to maintain only a low, or even possibly, a zero level of patrolling. Provided policy-makers can find a way of making these announcements credible – which may not be easy, as potential pirates presumably distrust policy-makers – one could, therefore, end up at the equilibrium with no patrolling and low piracy.

Relaxing Assumptions

We now briefly consider what could happen if some of the features above were violated, in particular, features (1) and (3). First, assume feature (1) is violated so that $n(0) = 0$. Now the piracy function shifts down so that it begins from the origin. Subject to the other three features holding, however, we could still have the two intersections described above, and three equilibria. There would, however, be one interesting change; the first equilibrium would now involve not only zero patrolling but also zero piracy. Given that piracy is zero, it is optimal to supply no patrolling, while pirate activity also (by our new assumption) is optimally zero as long as patrolling remains at zero. This only enhances the efficiency properties of this equilibrium. Of course, if the piracy function shifts down sufficiently – which can happen if returns to piracy go down dramatically for exogenous reasons – one or both of the other equilibria (ie other than the zero piracy, zero patrolling one) could disappear.[15] Note that an exactly similar analysis holds if the pirate activity function has an intercept on the *horizontal* axis, that is, if some positive level of p is necessary for pirate activity to reach a nonzero level.

Next, consider what happens when feature (3) is violated, subject to the other three features holding. For example, consider a policy response function where the policy-maker always maintains patrolling at some positive level $\underline{p}$ *even when* there is no pirate activity, and increases patrolling beyond this level with increases in pirate activity beyond zero. We then see that only the high-piracy high-patrolling equilibrium survives. The same holds true if we simultaneously change feature (1) allowing $n(0) = 0$. Only the high-piracy high-patrolling equilibrium survives; note that zero patrolling and zero piracy is no longer an equilibrium,

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[15] This seems unlikely to happen very soon, however, given the astronomical ransoms pirates are commanding.

because if piracy is zero, policy-makers still now respond with a positive level of patrolling. But if potential pirates expect a positive level of patrolling, they will, of course supply a positive level of piracy. Ironically, maintaining patrols even when there are no pirates is, in this analysis, counterproductive rather than helpful. (The same conclusion holds when there is no pirate activity below a positive level of patrolling, provided this level is less than $\underline{p}$).

Finally, drop feature (1), allowing $n(0)=0$, and simultaneously drop feature (3) but change it in a different way, so that the policy response function is now a strictly increasing function of pirate activity right from the level where $n=0$; there is no threshold property. In this case, there will be two equilibria. While the high-patrolling high-piracy equilibrium survives, there is also an equilibrium where zero levels of patrolling and pirate activity sustain each other.

3. A Dynamic Analogue

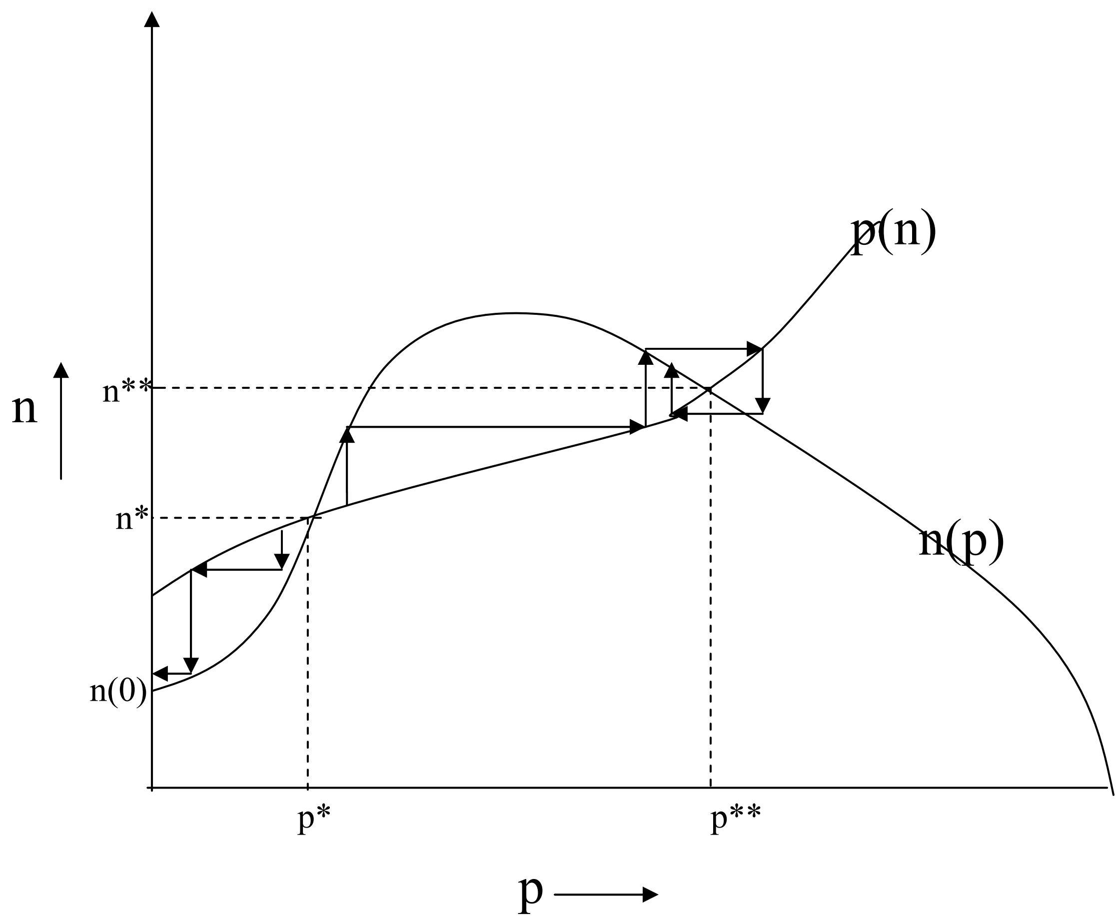
So far, we have only examined a static model. Making this model dynamic would allow us to examine issues of equilibrium stability, and not just existence. I continue to assume that the policy response function is described by (10) and (11), except that I now add time subscripts and lags to pirate activity and patrolling, so the policy response is $p_t = p(n_{t-1})$. While patrolling responds to pirate activity with a one-period lag, I also assume that pirate activity responds to patrolling with a one-period lag, so that $n_t = n(p_{t-1})$. Potential pirates have static expectations, wherein $E(p_t) = p_{t-1}$; in equilibrium, their expectations are fulfilled so that $p_t = E(p_t) = p_{t-1}$. Similarly, policy-makers also have static expectations, wherein $E(n_t) = n_{t-1}$; in equilibrium, their expectations are fulfilled so that $n_t = E(n_t) = n_{t-1}$

The equilibria of this system are as before. However, now we can draw inferences about stability.

Proposition 2: If pirate activity and patrolling respond to each other with a lag, and conditions are as described in Proposition 1, then the intermediate patrolling-intermediate piracy equilibrium is unstable.

Proof: From Figure 2, note that the policy response function cuts the piracy function from above at the intermediate patrolling-intermediate piracy equilibrium, with equilibrium values (p*, n*). It is easy to check that if p is slightly larger than p*, then the system diverges away from this equilibrium; as piracy and patrolling increase in step in the out-of-equilibrium adjustment. Similarly, if p is slightly smaller than p*, pirate activity declines and patrolling declines in step until the system reaches zero patrolling and a positive, but relatively low, level of pirate activity – in other words, till it stabilizes at our first equilibrium. This is illustrated in Figure 2. QED.

Figure 2: Adjustment Paths and Stability



Proposition 3: If pirate activity and patrolling respond to each other with a lag, and conditions are as described in Proposition 1, then the high piracy-high patrolling equilibrium with equilibrium values (p**, n**) is stable if (a) $n'(p)$ is still positive at this equilibrium, or (b) $n'(p)$ is negative at this equilibrium but $\frac{1}{p'(n)} > |n'(p)|$ (in which case the system converges to this equilibrium with damped oscillations). The zero patrolling-low piracy equilibrium with equilibrium values $(0, n(0))$ is also stable.

Proof: The first part of the Proposition follows from the fact that if the high piracy-high patrolling equilibrium also occurs on the upward sloping part of the piracy function, then the piracy function is necessarily gentler in slope in the neighborhood of the equilibrium than the inverse of the policy response function, $\frac{1}{p'(n)}$. We can check that this leads to stability. To verify the second part, note that if $\frac{1}{p'(n)} > |n'(p)|$, and we take values of p either slightly smaller or slightly larger than p**, the system converges to the equilibrium with damped oscillations (as in a cobweb model- this case is illustrated in Figure 2). The third part follows from the fact that if we consider slight increases in levels of patrolling beyond 0, the small resultant rise in pirate activity is insufficient to provoke policy-makers to supply patrolling, and we return to the equilibrium. QED.

From Propositions 2 and 3, we obtain a surprising result. Lowering patrolling below p* can be a good strategy, leading the system to a state with relatively low piracy and no patrolling at all. In contrast, raising patrolling beyond p* could quickly lead the system to settle into the high patrolling, high piracy equilibrium – if it is stable (either directly or with damped oscillations) – or could launch the system into ever-increasing oscillations (as if neither conditions (a) nor (b) of Proposition 3 are met). This reflects the fact that at intermediate levels of patrolling, pirate activity responds perversely to an increase in patrolling, partly a reflection of an income effect, and partly due to effects on the relative attractiveness of piracy and fishing.

4. Discussion and Conclusion

I have analyzed a model where the pool of potential pirates is homogeneous and divides its time between fishing and pirate activities. I conjecture that qualitatively similar results could be obtained with a model where the pool of potential pirates is heterogeneous in its distaste for violence but where each potential pirate chooses to specialize completely in either piracy or fishing. Then, pirate activity would simply be measured by the number of agents who became pirates rather than fishermen. Factors which made piracy more attractive relative to fishing would then mean that agents with more distaste for violence would also join the ranks of pirates.

The model shows that the deterrent effect of patrolling on pirate activity that one would expect to observe may be damped or even reversed by other factors. Even if increased patrolling depresses expected returns from piracy, it may also depress returns to the pirates' alternative occupation, fishing. Moreover, at intermediate levels of patrolling, a small increase in patrolling does not depress returns to piracy much because a pirate may be able to seize a higher loot in the event of a successful attack. These effects, combined with an income effect induced by increasing patrolling, make it plausible that over a range, pirate activity responds positively to patrolling.

In conjunction with a policy response that does not respond to low levels of piracy but responds positively and monotonically for higher levels, I show that multiple equilibria can obtain, making possible an equilibrium with no patrolling and low piracy, one with intermediate levels of both patrolling and piracy, and a high piracy, high patrolling equilibrium. Pirate activity may have begun to respond negatively to patrolling at or before the level of patrolling associated with the high-patrolling equilibrium ; however, piracy levels in this equilibrium would nonetheless remain high relative to the other equilibria. This explains why one may see high pirate activity and high patrolling co-exist in a sustained manner. If fishermen-pirates and policy-makers have static expectations and if pirate activity and patrolling respond with a lag to each other, I show that the middle equilibrium becomes unstable, while the higher one may be stable, as is the lowest one. This suggests that maintaining a level of patrolling in excess of p* may lead to a worse steady state outcome, involving higher levels of both piracy and patrolling. A low enough level of patrolling might on the other hand lead to an outcome where pirate activity diminishes (remaining positive) while patrolling shrinks to zero.

Appendix A

Deriving the policy response function

To start with, consider the case of an individual government as policy-maker. This could be the government of a large country whose citizens are significantly affected by piracy. This government has to decide whether and how much patrolling (p) to supply. Later we will show that this analysis can be easily extended to the case of multiple governments as (independent) policy makers.

The policy-maker chooses patrolling to maximize his political gains, net of any costs. Patrolling is costly, but also entails political gains. Moreover, the actual rate of pirate activity, n, directly affects the political gains to patrolling. The greater the rate of pirate activity, the stronger the political pressure whipped up by that country's citizens and media and the greater the policy maker's political gains from increasing patrolling. If there is no pirate activity at all, political gains to patrolling are zero (no one cares about a non-existent problem). For positive n, while political gains increase in p, they do so at a decreasing rate, i.e, the political gains function is concave in p, reflecting the fact that if patrolling is already very high, citizens are less keen that it increase further, (in view of the fact that it can then detract significantly from the resources available for other alternatives the citizens may be interested in). The policy maker's costs of patrolling increase in p at a non-decreasing rate, and have a fixed cost component; it is costly to send out any patrol at all, irrespective of the size of the patrol. However, the policy-maker will only supply a positive level of patrolling if his net gains from doing so are non-negative. Putting all this together, the policy maker chooses p to maximize

$$G(p,n)-C(p) \tag{A1}$$

subject to

$$G(p,n)-C(p)\geq 0 \tag{A2}$$

where $G(.,0)=0$, $G_p>0, G_n>0, G_{pn}>0, G_{pp}<0, C_p>0, C_{pp}\geq 0$ and[16]

$$C(p)=F+V(p) \tag{A3}$$

where the terms on the RHS of (A3) denote fixed and variable costs respectively. To derive the policy response function from these primitives, we proceed in two steps. In the first, we obtain the upward-sloping portion of the policy response function, assuming that constraint (A2) is satisfied. In the second, we derive the threshold property of the policy response function, focusing on constraint (A2).

Step 1: The first order condition gives us

$$G_p(p,n)=C_p(p) \tag{A4}$$

[16] $G_n>0$ captures the fact that the political gains from any given positive level of patrolling are higher when pirate activity is high. $G_{pn}>0$ captures the fact that the marginal political mileage gained by an increase in the level of patrolling is higher, the higher the level of piracy.

(A4) shows the policy maker's optimal policy response p to each possible level of piracy, n. Differentiate (A4) totally:

$$G_{pp}dp + G_{pn}dn = C_{pp}dp$$

$$\text{Or } p'(n) = \frac{dp}{dn} = \frac{G_{pn}}{C_{pp} - G_{pp}}$$

Optimal p is increasing in n, since $G_{pn} > 0$, $G_{pp} < 0$, and $C_{pp} \geq 0$. This establishes that subject to (A2), the policy response function is upward sloping.

Step 2: Using (A3), and substituting in the policy response function $p(n)$ derived from (A4), constraint (A2) can be written as

$$G(p(n), n) - V(p(n)) \geq F \tag{A5}$$

Now it is easy to show that the LHS of inequality (A5) is an increasing function of n. Differentiating the LHS totally with respect to n, we get

$$G_p p'(n) + G_n - V_p p'(n) = G_n > 0$$

(using the fact that $V_p = C_p = G_p$ by the first-order condition). Define $\underline{n}$ as the threshold value of n such that

$$G(p(\underline{n}), \underline{n}) - V(p(\underline{n})) = F \tag{A6}$$

Since the LHS of (A5) is increasing in n, we see that (A5) is not satisfied for n < $\underline{n}$. Hence, no patrolling is supplied below this threshold. To see that $\underline{n}$ > 0, note that (A5) is violated at n = 0. The LHS would then be 0 (using the fact that there would be no political gains, as no one cares about combating piracy when there is nothing to combat) while the RHS would be $F > 0$. Given that the LHS is a continuous and increasing function, therefore, there exists $\underline{n} > 0$ satisfying (A6). We now have both parts of our policy response function ;

$p(n) = 0, n < \underline{n}$

$p'(n) > 0, n \geq \underline{n}$

To clarify, consider an example.

Example: Consider $G(p,n) = n\sqrt{p}, C(p) = F + cp$. We can verify that these functions satisfy all the properties indicated above. Solving the first order condition for this case, we obtain

$p(n) = \frac{n^2}{4c^2}$. Substituting into the constraint (A2), we can solve for the threshold level of piracy as $\underline{n} = 2\sqrt{cF}$. Thus the policy response function here is

$p(n) = 0, n < 2\sqrt{cF}$,

$p(n) = \frac{n^2}{4c^2}$, $n > 2\sqrt{cF}$; the threshold depends on cost parameters.

Now consider extending the same analysis to a case where the patrolling level p is actually supplied by more than one country's government. Then each government independently decides on what patrolling level p_i it should supply, solving the same objective function as before. Assuming all governments have the same objective function, the only difference from the previous case is that p is the sum of all the p_i supplied by individual countries' governments. We will still see that each government responds only if n exceeds a threshold, but after that responds positively to a further increase in n. If different governments differ with respect to their cost parameters, the aggregate policy response function will still have a threshold (corresponding in this case to the lowest-cost country's threshold) and will still be upward sloping beyond this threshold. The upward slope would arise from two factors; the upward slope of individual countries' policy response functions, and the fact that as n increases further, a greater number of countries reach the threshold for sending out patrols.

Appendix B

When $P'(p) > 0$

In the text I have dealt with the domain where (5) is negative, ie, the return to piracy is decreasing in patrolling. Here I deal with the opposite case. Now, an increase in p actually raises the returns to piracy. This is possible only when $L'(p)$ is very large ; international vessels respond to greater security to such an extent that the possible prize that pirates can capture (with probability 1-p) goes up dramatically and is enough to offset the pirates' own greater probability of capture, loss of loot and punishment. Note however that equation (6) in the text still applies; thus assuming that $L''(p) \le 0$ (the booty that a successful pirate can capture is increasing at a non-increasing rate), we still have $P''(p) < 0$. Now the returns to piracy increase with patrolling, but at a decreasing rate. Given that the returns to fishing are decreasing with patrolling, the direct effect of an increase in p is to raise the relative returns to piracy, more sharply than in the case dealt with in the text ; $P'(p)-r'(p)$ is positive and may be large. However, equation (8) still holds so that though the relative return to piracy is rising, it is doing so at a falling rate. Interpreting (9), we now have two differences from the case in the text. First, as $P'(p)-r'(p)>0$, the direct effect of increasing p is to raise $\alpha *$ by increasing the attractiveness of piracy relative to fishing. This effect now unambiguously increases $\alpha *$. Secondly, the income effect is now different. As a rise in p actually raises income earned from piracy (though it depresses income from fishing) it may, particularly for large α, encourage people to spend less time in piracy and more time in the less lucrative, non-violent alternative. This factor thus tends to make $\alpha *$ fall once it becomes large. Part (b) of observation 1 remains the same, and condition (7) is actually not needed for part (c). The effect of positive $P'(p)-r'(p)$, combined with the fact that when time spent in piracy is small, the income effect of a rise in p is concentrated in fishing, whose returns fall – hence encouraging people to turn to the more lucrative option, piracy – ensure that $\alpha *$ always increases with p for a non-empty range when p is small. Therefore, even when $P'(p)>0$, we obtain a hump-shaped piracy activity function, and can hence obtain similar results regarding multiple equilibria. The chief reason for exclusion of this case from the analysis in the text is that the effects which tend to make the return to piracy rise with p are second-order effects, while those which tend to make this return fall with p are first-order effects. Hence, I consider the case in the text to be the more likely one, though the case analyzed here is a theoretical possibility, particularly given that S can be very light.

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