“Security in the Absence of a State” Supplemental Appendix

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Abstract

This Supplemental Appendix to the paper titled “Security in the Absence of a State: Traditional Authority, Livestock Trading, and Maritime Piracy in Northern Somalia ” presents (i) summary statistics for the data used in the paper, (ii) results from the strategy of estimating the exports-piracy relationship using the dates of the Hajj as an instrument, and (iii) the formal model discussed in Section 3 of the main text.

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1 Summary Statistics

Table 1: Summary statistics

	Somaliland				
	Mean	Std. Dev.	Min	Max	Obs.
Pirate attacks	1.35	2.08	0	11	157
Conflict incidents	3.94	5.29	0	29	155
Livestock exports	9.16	2.19	0	12.09	156
Local meat prices	0.02	0.48	-1	1	125
Int'l meat prices	0.02	0.55	-1	1	175
	Puntland				
	Mean	Std. Dev.	Min	Max	Obs.
Pirate attacks	1.32	2.15	0	14	157
Conflict incidents	5.75	7.93	0	44	155
Livestock exports	9.27	1.93	0	10.9	156
Local meat prices	0.09	0.45	-1	1	136
Int'l meat prices	0.02	0.55	-1	1	175

2 IV Estimates

Estimating the direct relationship between livestock exports and piracy attacks is difficult since many unmeasured factors may affect both export volume and piracy attacks. Monthly fluctuations in livestock exports suggest that there may be seasonal factors at play, which could affect both piracy and livestock exports. One such factor is current weather conditions, which might not be sufficiently controlled for by our monsoon dummy, and which may simultaneously decrease the ability of pirates to carry out attacks while decreasing the volume of livestock offered for export. For example, in periods of plentiful rainfall and ample grazing forage, pastoralists face less pressure to sell their animals to purchase food (Umar and Baulch, 2010). At the same time, heavy rains make it harder to undertake pirate attacks. If both livestock exports and pirate attacks are higher in periods of limited rainfall, this unobserved factor may lead us to spuriously underestimate the negative relationship between exports and piracy.

To address the possibility of such confounding, we examine how exogenous variation in demand for livestock due to the annual Hajj affects exports and, in turn, piracy. Since the Hajj is scheduled by reference to the Islamic lunar calendar, which is shorter than the Gregorian calendar, its timing is plausibly exogenous to pirate attacks as well as longer term seasonal weather that may affect piracy. This makes it a reasonable candidate as an instrument for exports, albeit with some major caveats. In particular, the exclusion restriction – that piracy incidents are affected by the Hajj via the livestock export route alone – may be violated in other ways. For example, one might argue that, given Somali pirates are Muslim, they may reduce the organization of piracy activities during particularly salient religious periods. Although this "pious pirate" argument does not appear to find support elsewhere in our data (in particular, pirate attacks are no less likely on Fridays) we cannot rule out this possibility so we must interpret the results of this strategy with equal caution.[1]

Table 2 shows the results from this instrumental variables estimation strategy. All models include lagged exports and year dummies to control for changes in export volumes across time. The first notable result is the positive coefficient of the Hajj indicator on export volumes across all first stage models in the lower panel. As expected, the Saudi livestock ban attenuated the relationship between the instrument and exports during the ban, which can be seen by comparing the coefficient estimates during and after the ban for each port. This attenuation is

[1] For example, one might argue that the lack of any Friday effect may be not rule out the pious pirate argument, if the Hajj is a more important religious commitment than Friday prayers. We do not find this explanation compelling since Muslims are only expected to undertake Hajj at most once during their lifetime, and only a small number of Somalis actually perform the Hajj each year (less than 7,500 did so in 2015, "Somali Hajj pilgrims reluctant to return home", *Saudi Gazette*, 10/15/2015). So it seems unlikely that any significant proportion of Somali pirates are observing Hajj each year, but since we cannot rule it out, we acknowledge the importance of erring on the side of caution in interpreting these estimates as causal.

Table 2: Instrumental Variables Estimates of Pirate Attacks

Second Stage IV Results	*Somaliland (Berbera)*			*Puntland (Bosaso)*		
DV = Pirate Attacks	All	During Ban	After Ban	All	During Ban	After Ban
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged Pirate Attacks	0.0370	-0.0922	0.0513	-0.0121	0.00566	-0.276†
	(0.0429)	(0.0827)	(0.0393)	(0.0378)	(0.0391)	(0.161)
First Stage Residuals	0.401	0.274	1.352**	0.0821	-0.0931	0.987
	(0.246)	(0.304)	(0.485)	(0.183)	(0.197)	(1.026)
Exports (log)	-0.568*	-0.492†	-1.061*	-0.128	-0.0156	0.105
	(0.230)	(0.288)	(0.445)	(0.170)	(0.199)	(0.550)
Monsoon	0.205	0.0802	0.158	-0.215	-0.325	-0.347
	(0.227)	(0.315)	(0.357)	(0.204)	(0.228)	(0.487)
Unskilled Wage Rate	-0.261	0.375	-0.656	-0.262	-0.462	-0.219
	(0.337)	(0.546)	(0.402)	(0.331)	(0.470)	(0.475)
Constant	7.380**	4.422	14.33**	2.592	2.822	0.382
	(2.216)	(2.783)	(4.493)	(1.735)	(1.956)	(5.068)
Observations	127	89	38	143	105	38
Pseudo R^2	0.147	0.137	0.130	0.141	0.184	0.045
Log-Likelihood	-173.7	-96.02	-72.36	-201.3	-141.8	-56.09
AIC	387.3	232.0	184.7	442.5	323.6	152.2

First Stage IV Results	*Somaliland (Berbera)*			*Puntland (Bosaso)*		
DV = Exports (log)	All	During Ban	After Ban	All	During Ban	After Ban
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged Exports (log)	0.786**	0.839**	-0.107	0.682**	0.698**	-0.165
	(0.0901)	(0.0888)	(0.100)	(0.131)	(0.133)	(0.173)
Hajj	0.521*	0.227	1.797**	0.751**	0.731*	0.959**
	(0.212)	(0.209)	(0.199)	(0.225)	(0.299)	(0.102)
Constant	1.639†	1.477†	11.05**	2.585†	2.829*	11.18**
	(0.872)	(0.855)	(1.016)	(1.445)	(1.267)	(1.676)
Observations	155	117	38	155	117	38
R^2	0.778	0.787	0.733	0.676	0.678	0.590
F Statistic	16.67	21.08	19.72	6.511	8.514	26.99

Note: Two stage IV results. Second stage results, reported in the upper panel, are negative binomial estimates of pirate attacks. These models include year fixed effects, and robust standard errors are reported in parentheses. OLS estimates of livestock exports. All models, both first and second stage, include year fixed effects and robust standard errors are reported in parentheses. † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

particularly acute for Somaliland, demonstrating the importance of the Saudi livestock market for Somaliland's Berbera port.

We report the second stage estimates in the upper panel of Table 2. Given that we use a negative binomial model for the pirate attack count data, we use the second-stage residual inclusion method for non-linear models proposed by Mullahy (2007), which provides a way to control for unmeasured confounders in the second stage. Our interest is in the coefficient of the log of exports (third row). The upper panel shows how the estimates for each region follow our expectation. There is a negative relationship between exports and pirate attacks in Somaliland, consistent with the argument that pirates self-regulate their piracy therein. This relationship is especially strong after the Saudi ban ended and Somaliland's export market expanded. The larger size of the estimates in Table 2 as compared to Table 1 in the main text indicate that unobserved factors do lead us to underestimate the negative relationship between exports and piracy in the first Table. In Puntland, there is no evidence of such a relationship, consistent with the lack of coordination between Puntland's diverse economic interests.

3 Formal Model

Our model simplifies the northern Somali economy into two sectors, livestock trading and piracy, and Somali society into two groups based on clan heritage— those that rely comparatively more on the livestock trade for income and those that rely comparatively more on piracy. While our discussion in the main text recognizes that economic interests and occupational choices do not perfectly delineate along clan boundaries, we will for simplicity refer to these groups as "livestock traders" and "pirates."[2]

The population share of the traders is λ while the share of the pirates is $1-\lambda$. The parameter $\Lambda = \lambda/(1-\lambda)$ denotes the ratio of these population shares. The two groups interact repeatedly over time. Time is discrete with an infinite horizon and indexed by t. Both groups discount future payoffs with a common discount factor $\delta < 1$.

3.1 Fundamentals

In each period the two groups move simultaneously, deciding whether or not to cooperate with each other.

At the start of each period t a state $s_t \in \{0,1\}$ is drawn to determine whether trade is productive, with $s_t = 1$ indicating the realization of the high productivity state. We assume that s_t is independently drawn across periods and that the probability that $s_t = 1$ is a constant θ for all t. When the traders cooperate, they make peace with the pirates and each trader shares a fraction ϕ_t of his income with the pirating group, where $0 \leq \phi_t \leq \bar{\phi}$ and $\bar{\phi}$ is an exogenous parameter. When the traders do not cooperate, they do not share any of their income, and conflict takes place between the two groups. Under conflict, each member of the

[2]As we have noted, members of any single Somali clan are likely to be engaged in a variety of economic activities. The claim here is simply that some groups have a greater economic interest in the livestock trade, while others may have a greater interest in piracy. For simplicity, we refer simply to trading groups and pirate groups, but this should not be taken to imply that *all* members of the group are engaged in that single activity.

pirating group incurs a cost $k\Lambda > 0$ while each member of the trading group incurs a cost k/Λ.[3] The key feature of this assumption is that the cost that one group can inflict upon each member of the other group is larger the more the first group outnumbers the second.

When the pirates cooperate, they self-regulate the number of pirate attacks that they launch. By doing this, they are foregoing some of the returns from piracy, but they may be providing considerable benefits to the traders by creating a safer trading environment during periods of highly productive trade. When the pirates choose not to cooperate, they engage in unregulated piracy, creating a negative externality on productive trade in these periods.

More precisely, suppose that when productivity is low the income of each trader from productive trade is 0 regardless of what the pirates do. When productivity is high, the income of each trader is a random variable R_t which can be high or low, and whose distribution is determined by the pirating group's choice of whether or not to regulate piracy. In particular, we assume that $R_t \in \{0, R\}$ with $0 < R$, and the probability that R_t will equal 0 is $\underline{\gamma} > 0$ if the pirates self-regulate in period t, and $\overline{\gamma} > \underline{\gamma}$ if they do not. $R_t = R$ with complementary probability in either case, and R_t is realized at the end of the period.

To capture the idea that the self-regulation of piracy is costly for the pirates, we assume that the pirates have a lower chance at making a high return from piracy if they self regulate. In each period, each pirate receives a return of $d_t \in \{0, d\}$ from piracy in period t, where $0 < d$. When they do not self regulate in period t, each pirate makes the high return of $d_t = d$ with probability $\overline{\mu}$ and the low return of $d_t = 0$ with probability $1 - \overline{\mu}$. The expected return from not self regulating is thus $\overline{\mu}d$. When they do self-regulate, each pirate receives the high return $d_t = d$ with probability $\underline{\mu}$, and the normalized low return of $d_t = 0$ with probability $1 - \underline{\mu}$. The expected return from self-regulation is thus $\underline{\mu}d$. The assumption that $\underline{\mu} < \overline{\mu}$ says that self-regulation lowers the probability that the pirates will receive the high return $d_t = d$.

3.2 Monitoring Structure

We assume that the model has one-sided moral hazard: the pirates' decision to regulate piracy is not directly observed by the traders. This assumption is motivated by the fact that piracy is often, but not always, an activity that is planned and carried out in a way that may not be publicly observable. In particular, it is difficult for the trading group based on land to always know how much piracy is going on at sea, and where it is being targeted.

In our model, the traders have access to two noisy public signals of whether or not the pirates are self regulating: the pirates' period t income from piracy, and the traders' own period t revenue from trade, both of which are observed at the end of the period. Since the

[3]To motivate these costs, imagine that each individual can produce a cost k. There are λ traders, so the traders together produce λk. This cost is equally divided among all members of the pirating group, so the cost incurred by each member of the pirating group is $\lambda k/(1-\lambda) = k\Lambda$. Similarly, the pirates produce a total cost of $(1-\lambda)k$ and each trader incurs cost $(1-\lambda)k/\lambda = k/\Lambda$.

low revenue $R_t = 0$ is more likely when the pirates don't self regulate than when they do, it is evidence of unregulated piracy. Similarly, the high return $d_t = d$ is more likely when the pirates do not self-regulate than when they do, and is also evidence of unregulated piracy.

We define $\omega_t \in \{0, 1\}$ to be the period t indicator of a high income from piracy in the previous period, $d_{t-1} = d$. Thus $\omega_t = 1$ with probability $\underline{\mu}$ if the pirates self-regulated in the previous period, and with probability $\overline{\mu}$ if they did not. $\omega_t = 0$ with complementary probability in either case. Finally, we assume that if the traders learn that the pirates did not self-regulate in the previous period ($\omega_t = 1$), then by choosing conflict each trader receives an additional payoff worth g, while each pirate incurs a loss of l. If $\omega_t = 0$ then there are no additional gains or losses to either group. For example, we could set $g = h + \beta d/\Lambda$ and $l = (\alpha - \beta)d$ with the following interpretation. If a pirate earns d from piracy in the previous period, then the traders loot $\beta d \geq 0$ of this income, dividing it equally among themselves. $\alpha d > 0$ is the value of the previous period return in the current period. $h \geq 0$ represents any social motives for sanctioning unregulated piracy.[4] We set $\omega_0 = 0$.

3.3 Payoff Structure and Assumptions

The expected payoffs per individual in each group have the following structure, where the row player is the trading group and the column player is the pirate group:

	self-regulate	don't self-regulate
peace	$(1-\phi_t)(1-\underline{\gamma})s_tR,\ \underline{\mu}d + \phi_t(1-\underline{\gamma})s_tR\Lambda$	$(1-\phi_t)(1-\overline{\gamma})s_tR,\ \overline{\mu}d + \phi_t(1-\overline{\gamma})s_tR\Lambda$
conflict	$(1-\underline{\gamma})s_tR + \omega_t g - k/\Lambda,\ \underline{\mu}d - \omega_t l - k\Lambda$	$(1-\overline{\gamma})s_tR + \omega_t g - k/\Lambda,\ \overline{\mu}d - \omega_t l - k\Lambda$

These payoffs are subject to the assumptions above as well as three additional assumptions, two of which are as follows. (The third will be stated later.)

(A1) $g - k/\Lambda > 0$

(A2) $d > l + k\Lambda$

We use the first assumption to establish that the traders have short-run incentives to sanction piracy despite the costs of conflict if they expect the pirates to not self-regulate. We use the second one to establish that if piracy is successful, then the income that it generates is high in comparison to the potential costs of being punished for it; this gives myopic pirates a short run incentive to not self-regulate.

[4] Since we allow $h = 0$ or $\alpha = 0$ we are agnostic as to whether the traders have short run incentives to choose conflict after evidence of piracy in order to obtain a share of the pirate income, or to sanction the pirates for anti-social / immoral behavior; or, for both reasons.

3.4 Social States

We have described a stochastic game with imperfect public monitoring. If the players are patient (δ is high) then the game has a large set of equilibria exhibiting varying degrees of cooperation between the two groups (Hörner et al., 2011). However, in all equilibria, periods of conflict take place. In addition, the structure of the most efficient equilibrium can be quite complex.[5] Therefore, instead of seeking a characterization of the socially optimal self-enforcing agreement, we focus on particular modes of cooperation that help us make sense of the data.

Our strategy for analyzing the game will be to take an approach that focuses on particular kinds of social agreements, i.e. strategy profiles. We characterize the conditions that make these agreements incentive compatible. The equilibrium concept, as usual, is perfect public equilibrium (PPE).

We characterize social agreements using three categories of "automaton states" and derive conditions that are necessary and sufficient to sustain particular "path automata" in equilibrium. Informally, a path automaton specifies actions that are chosen only on the path of play.[6] As such, it is an incomplete description of a strategy profile. Our approach is to characterize conditions under which there exists a way to complete the description of the strategy profile such that it becomes an equilibrium of the game for high values of the discount factor.[7] The following describes the three categories of automaton states.

1. *Conflict* : In these states, the traders choose conflict and therefore they do not share any of their income with the pirates. Note that there are several possible automaton states in this category, depending on whether the payoff relevant signal ω_t equals 0 or 1, whether s_t equals 0 or 1, and whether the pirates self-regulate or don't.

2. *Peace and no self-regulation* : In these states, the traders make peace with the pirates but the pirates do not self-regulate. If $s_t = 1$, then this creates a negative externality on productive trade because it lowers the probability that the traders will obtain the high return ($R_t = R$) from $1-\underline{\gamma}$ to $1-\overline{\gamma}$. If $s_t = 0$ then unregulated piracy has no externality on productive trade (since $R_t = 0$ for sure). Note that there is a continuum of such states depending on the fraction ϕ of income that is shared.

3. *Peace and self-regulation* : In these states, the traders make peace with the pirates and the pirates self-regulate. The pirates are forgoing some of the expected returns from piracy by lowering their chance of obtaining the high return ($d_t = d$) from $\overline{\mu}$ to $\underline{\mu}$.

[5]See, e.g., Abreu, Pearce and Stacchetti (1990) for an analysis of repeated games with imperfect monitoring, and Hörner et al. (2011) for an analysis of stochastic games with imperfect monitoring in case of $\delta \to 1$.

[6]Kandori and Obara (2010) give a formal definition of path automata.

[7]We follow the literature on cooperation in repeated games by focusing on high values of the discount factor. To support the path automata that we study here for lower values of the discount factor, we typically require stronger conditions.

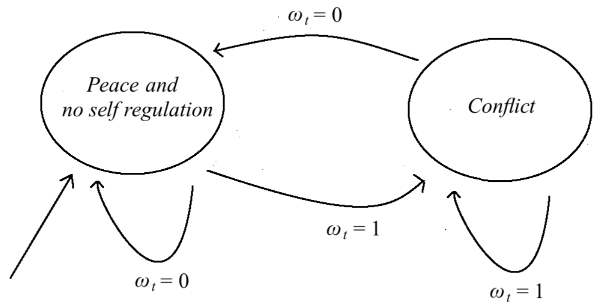

Figure 1: No Cooperation Regime (Puntland)

During high productivity periods ($s_t = 1$) they are conferring a benefit to the traders by increasing the traders' chances of earning the high return ($R_t = R$) from $1 - \overline{\gamma}$ to $1 - \underline{\gamma}$. During low productivity periods ($s_t = 0$) they are conferring no benefit upon the traders, since $R_t = 0$ independent of what they do. Again, there is a continuum of such states depending on the fraction ϕ of income that is shared.

3.5 Cooperation and No Cooperation Regimes

We now describe two types of regimes—one that we call the "No Cooperation Regime" (NCR) in which the pirates do not self-regulate, and another that we call a "Some Cooperation Regime" (SCR) in which they do. These correspond to different classes of path automata.

NCR Suppose that the players are myopic ($\delta = 0$) and consider a situation in which no income is ever shared ($\phi_t = 0$ for all periods t in which the traders make the choice). The pirates would never self-regulate, due to the fact that $\overline{\mu} - \underline{\mu} > 0$. This results in a negative externality on productive trade during the high productivity periods. The traders would then choose peace when $\omega_t = 0$ and conflict when $\omega_t = 1$, by assumption (A1). Transitions between automaton states in this regime are depicted in Figure 1. Society begins in a *Peace and no self-regulation* state. In any period $t > 0$, if $\omega_t = 0$ then society is in a *Peace and no self-regulation* state; but if $\omega_t = 1$ then society is in a *Conflict* state in which the pirates choose not to self-regulate. This describes the NCR. In the appendix, we show that under assumption (A2) the NCR describes a path automaton that is supported by a PPE for all values of δ.

SCR Now we describe two versions of the SCR, both of which are represented in Figure 2. In both versions, the following describes which of the three categories of states society is in for any period t. (Note that these are only rules governing on-path play.)

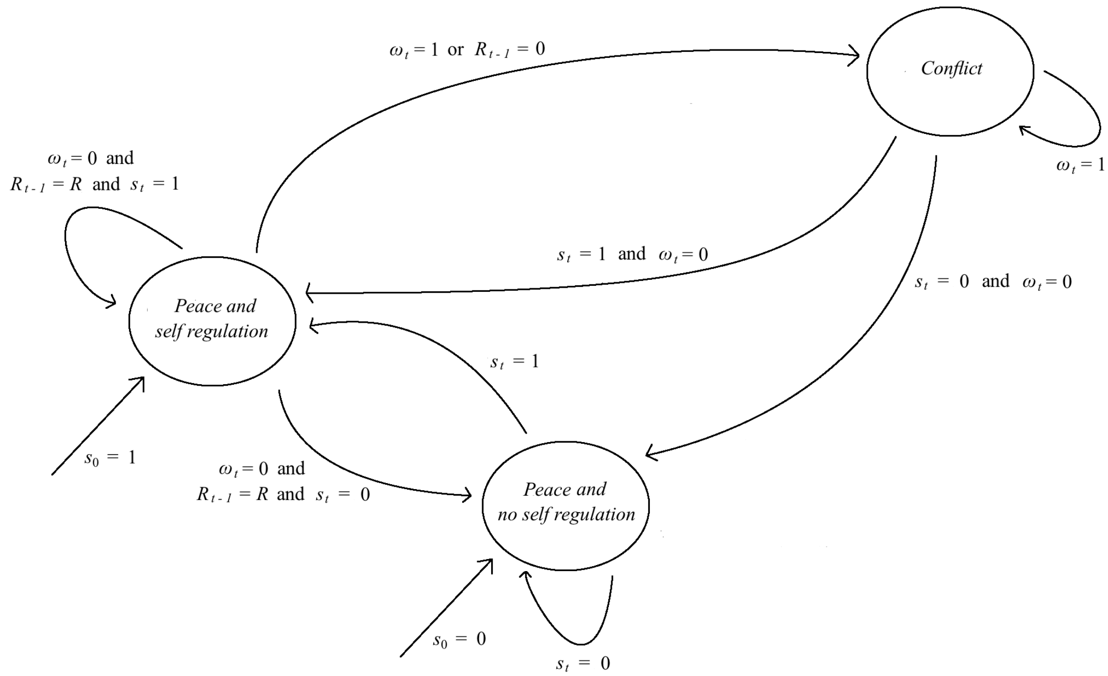

Figure 2: A Some Cooperation Regime (Somaliland)

1. Consider the following situations: (i) $t = 0$ and $s_t = 1$, (ii) $R_{t-1} = R$, $\omega_t = 0$, $s_t = 1$ and society was in a *Peace and self-regulation* state in period $t-1$, and (iii) $\omega_t = 0$, $s_t = 1$ and society was in a *Conflict* state in period $t-1$. In all of these situations, the pirates choose to self regulate and the traders make peace, sharing a fraction $\phi_t = \bar{\phi}$ of their income. Thus, society is in a *Peace and self-regulation* state in period t.

2. Consider the following situations: (i) $t = 0$ and $s_t = 0$, (ii) $R_{t-1} = R$, $\omega_t = 0$, $s_t = 0$ and society was in a *Peace and self-regulation* state in period $t-1$, and (iii) $\omega_t = 0$, $s_t = 0$ and society was in a *Conflict* state in period $t-1$. In all of these situations, the pirates choose to not self regulate and the traders make peace with the pirates. (They share any fraction of their income since they are guaranteed to have $R_t = 0$.) Thus, society is in a *Peace and no self-regulation* state in period t.

3. Consider the following situations: (i) $R_{t-1} = 0$ or $\omega_t = 1$ and society was in the *Peace and self-regulation* state in period $t-1$, and (ii) $\omega_t = 1$ and society was in a *Conflict* state in period $t-1$. In both situations, society is in a *Conflict* state in period t.

Thus in both versions of the SCR, there is maximal revenue sharing at the level $\bar{\phi}$ whenever society is in *Peace and self-regulation*. The two versions of the SCR differ only in whether the *Conflict* states that are reached involve the pirates self-regulating their pirate activities or not.

In one version of the SCR, which we will call SCR[SR], the pirates self-regulate on the path of play whenever the traders choose conflict. In the other version, which we call SCR[nSR], the pirates choose to not self-regulate on the path of play whenever the traders choose conflict.

3.6 Supporting the Regimes in Equilibrium

In an equilibrium, neither the pirates nor the livestock traders have a profitable one-time deviation from any of the automaton states that occur on the path of play. Deviations by the the livestock traders are perfectly observable, so their incentive to not deviate from the SCR can be provided by a switch to the NCR provided that the NCR gives a lower payoff to them than the SCR. To focus our attention on the monitoring problems that complicate the incentives of the pirates to not deviate, we make an assumption that guarantees that the livestock traders' payoff from either SCR exceed their payoff from the NCR for all values of δ high enough. This is our third assumption:

(A3) $\theta\left[(1-\bar{\phi})(1-\underline{\gamma})R-\left(1+\frac{1}{1-\underline{\mu}}\right)(1-\overline{\gamma})R\right]\geq[1+\underline{\gamma}(1-\underline{\mu})\theta]g+k/\Lambda$

Since the right side of (A3) is positive, this implies that the left side is positive. Therefore, the ex ante expected income to livestock traders when they share the maximum amount under *Peace and self-regulation* (i.e., the quantity $\theta(1-\bar{\phi})(1-\underline{\gamma})R$) exceeds the ex ante expected income from *Conflict* in the NCR (i.e., the quantity $\theta(1-\overline{\gamma})R$). When this is the case, assumption (A3) is more likely to hold when R is high in comparison to g and k/Λ. That is, the assumption implies that revenue from the livestock trade is important to the traders in comparison to their other payoff considerations.

The following proposition the summarizes our main result.[8]

Proposition 1. *1. There is a PPE that supports the NCR for all values of the discount factor δ.*

2. There exist three continuous real valued functions f_C, f_{nSR} and f_{SR} over the parameters of the model with the following properties: (i) there is a PPE that supports the SCR[nSR] for all high values of δ if and only if $f_{nSR}>0$ and $f_C>0$, (ii) there is a PPE that supports the SCR[SR] for all high values of δ if and only if $f_{SR}>0$ and $f_C<0$, and (iii) f_{nSR} and f_{SR} are both increasing in Λ and $\bar{\phi}$ and decreasing in d.

We prove this proposition in Section 3.8 below. Before that, we interpret it and briefly remark on its implications.

Parts (i) and (ii) imply that either the SCR[nSR] or the SCR[SR] can be supported in equilibrium for high values of the discount factor, but not simultaneously both. In the proposition, $f_C>0$ represents the condition that says that the pirates have no profitable one-time

[8]The proposition refers to the parameters of the model, which are θ, $\overline{\mu}$, $\underline{\mu}$, $\overline{\gamma}$, $\underline{\gamma}$, Λ, $\bar{\phi}$, g, l, d, k and R.

deviations from any of the *Conflict* states of the SCR[nSR] that arise on the path of play. If $f_C < 0$, they have no profitable one-time deviations from any of the *Conflict* states that arise on the path of the SCR[SR].

Similarly, $f_{nSR} > 0$ represents the condition that says that the pirates have no profitable one-time deviations from the *Peace and self-regulation* state that arises on the path of play of the SCR[nSR] and $f_{SR} > 0$ is the condition that says that the pirates have no profitable one-time deviations from the *Peace and self-regulation* state that arises on the path of play of the SCR[SR]. Since part (iii) says that f_{nSR} and f_{SR} are both increasing in Λ and $\bar{\phi}$, it is easier to provide incentives to the pirates to not deviate from the *Peace and Self Regulation* state on the path of play of either SCR[nSR] or SCR[SR] when the traders significantly outnumber the pirates, and when they are able to share higher fractions $\bar{\phi}$ of their income from trade. Since these functions are also decreasing in d, as piracy becomes more lucrative, the pirates have greater incentive to deviate from self-regulating in both the SCR[nSR] and SCR[SR].

3.7 Putting the Model into Context

Our explanation for the different development trajectories of Somaliland and Puntland is that the two regions of Somaliland and Puntland differ in terms of the fundamental parameters of the model, notably $\bar{\phi}$ and Λ. The ratio of economic interests favors the livestock trade more in Somaliland, thus Λ is higher in Somaliland than in Puntland. Similarly, as we argued previously, there is a greater degree of revenue sharing among clans in Somaliland than in Puntland, making it likely that $\bar{\phi}$ is higher in Somaliland than it is in Puntland. This suggests, in light of the comparative statics of the previous section, that it is harder to provide the pirates of Puntland with the incentive to self-regulate their piracy than it is to provide the pirates of Somaliland with these incentives. Consequently, our theory is that the SCR better describes the relationship between traders and pirates in Somaliland while the NCR better describes the relationship between these two groups in Puntland. Furthermore, it may not be possible to replicate the cooperative agreement that is in place in Somaliland in Puntland since the differences in Λ and $\bar{\phi}$ across the regions suggest that the Somaliland agreement may not be *self-enforcing* in Puntland.

We now compare the two regimes in terms of their testable predictions for Somaliland and Puntland. We focus on explaining the variation in piracy and conflict.

Piracy Piracy takes place in an unregulated way under the NCR and the pirates are able to make successful attacks with probability $\overline{\mu}$ in each period. We take this to represent the frequency of piracy under the NCR. Under either SCR, on the other hand, piracy is self-regulated in the *Peace and self-regulation* state, so on average pirates make successful attacks with probability smaller than $\overline{\mu}$ in each period. Thus, the frequency of attacks is strictly lower under either of the two SCRs than under the NCR. This comports with the fact reported in

Section 2 of the main text that there is more piracy off the coast of Bosasso in Puntland than there is off the coast of Berbera in Somaliland.

In addition, under the SCR pirating attacks are more frequent when livestock exports are low and less frequent when livestock exports are high, whereas under the NCR there is no relationship between livestock exports and the timing of pirating attacks. The reason is that the SCR represents a social agreement that is designed to mitigate the externality caused by pirating attacks on the livestock trade. When trade is low, there is almost no externality so there is no reason for the livestock traders to want the pirates to self-regulate, and for the pirates to do so. Given this, we expect to see a negative relationship between livestock exports and piracy off the coast of Berbera in Somaliland. By contrast, the relationship between livestock exports and pirate attacks off the coast of Bosasso in Puntland should be much weaker, because the distribution of interests in Puntland is such that groups are unable to reach an agreement whereby piracy will always be regulated in periods when livestock revenues are high.

Conflict What fraction of time do the two societies spend in the *Conflict* automaton states in the long run? This quantity can also be derived by finding the stationary distribution of the Markov process governing state transitions when players implement the paths associated with the NCR and either of the SCRs. The quantity is given by $\overline{\mu}$ under the NCR, by $\theta\kappa/(1-\overline{\mu}+\theta\kappa)$ under the SCR[nSR], and by $\theta\kappa/(1-\underline{\mu}+\theta\kappa)$ under the SCR[SR], where $\kappa := \underline{\mu}+\underline{\gamma}(1-\underline{\mu})$. Therefore, if $\underline{\gamma}$ is small enough, society spends less time in conflict under either of the SCRs than it does under the NCR. The assumption $\underline{\gamma}$ is small (i.e. society is relatively unlikely to enter conflict as a result of a downward income shock for the livestock traders) is natural, and comports with the evidence that we present in the main text.[9]

As well as differing with regards to the amount of conflict that occurs, the NCR and SCR also differ in terms of when conflict starts. Under the NCR conflict takes place after pirating attacks since the pirates bring back income that creates a windfall of resources to compete over, and/or because of the social incentives to sanction piracy. Under both SCRs, there is also a relationship between conflict and pirating attacks but because attacks are less frequent, the relationship is subject to more noise. If pirating attacks occur only when piracy does not hurt the livestock trade, for example, there should be only a weak relationship between pirating attacks and conflict. Conflict does take place, however, after a sharp decline in livestock revenue since the livestock traders use conflict as a means to provide incentives to not launch too many pirate attacks. As a result, we expect that in both Puntland and Somaliland, conflict increases after pirating attacks, but the relationship is clearer in Puntland. We also expect that in Somaliland, conflict takes place after a sharp decline in livestock revenue, while in Puntland there is no relationship between livestock revenue and conflict.

[9]See, e.g., Figure 3 in the main text, which shows less overall conflict in Somaliland than in Puntland.

3.8 Proof of Proposition 1

A PPE supports a path automaton if, on the path of play, the PPE prescribes the same action choices that are prescribed by the path automaton.

We organize the proof as follows. We first characterize the payoffs for each group in each automaton state of the NCR, SCR[nSR] and SCR[SR]. Second, we prove part 1 of the proposition. Third, we define the functions f_C, f_{SR} and f_{nSR}. In so doing, we establish the comparative statics reported in part 2(iii). Finally, we prove parts 2(i) and 2(ii).

3.8.1 Payoffs

We characterize all payoffs as solutions to a recursive system of equations. In each case, the system of equations has a unique solution so all payoffs are unique.

NCR payoffs Let $V^p_{NCR}(PnSR)$ denote the value function for the pirates at the *Peace and no Self Regulation* state and $V^p_{NCR}(C)$ their value function at the *Conflict* state when $\omega = 1$. Under the NCR these value functions satisfy the following recursive system of equations

$$\begin{aligned} V^p_{NCR}(PnSR) &= (1-\delta)(\overline{\mu}d) + \delta \mathcal{V}^p_{NCR} \\ V^p_{NCR}(C) &= (1-\delta)(\overline{\mu}d - l - k\Lambda) + \delta \mathcal{V}^p_{NCR} \end{aligned} \tag{1}$$

where

$$V^p_{NCR} := (1-\overline{\mu})V^p_{NCR}(PnSR) + \overline{\mu}V^p_{NCR}(C)$$

is the continuation value from each state. Similarly, to compute the values of the livestock traders, let $V^\ell_{NCR}(PnSR|s)$ denote their value in the *Peace and no Self Regulation* state when $s_t = s$ and $V^\ell_{NCR}(C|s)$ their value under the *Conflict* state when $s_t = s$. These values solve the following system of equations

$$\begin{aligned} V^\ell_{NCR}(PnSR|0) &= (1-\delta)(0) + \delta \mathcal{V}^\ell_{NCR} \\ V^\ell_{NCR}(PnSR|1) &= (1-\delta)((1-\overline{\gamma})R) + \delta \mathcal{V}^\ell_{NCR} \\ V^\ell_{NCR}(C|0) &= (1-\delta)(g - k/\Lambda) + \delta \mathcal{V}^\ell_{NCR} \\ V^\ell_{NCR}(C|1) &= (1-\delta)\big[(1-\overline{\gamma})R + g - k/\Lambda\big] + \delta \mathcal{V}^\ell_{NCR} \end{aligned} \tag{2}$$

where

$$\mathcal{V}^\ell_{NCR} \equiv \theta\big[\overline{\mu}V^\ell_{NCR}(C|1) + (1-\overline{\mu})V^\ell_{NCR}(PnSR|1)\big] + (1-\theta)\big[\overline{\mu}V^\ell_{NCR}(C|0) + (1-\overline{\mu})V^\ell_{NCR}(PnSR|0)\big]$$

is the continuation value from each state.

SCR[nSR] payoffs Now consider the SCR[nSR] and let $V^p_{SCR[nSR]}(C|\,\omega)$ denote the value of the pirates in the *Conflict* state when the payoff relevant signal realization is $\omega \in \{0,1\}$, $V^p_{SCR[nSR]}(PnSR)$ their value in the *Peace and no Self Regulation* state, and $V^p_{SCR[nSR]}(PSR)$ their value in the *Peace and Self Regulation* state. These value functions satisfy the following recursive system of equations:

$$
\begin{aligned}
V^p_{SCR}(C|\,0) &= (1-\delta)(\overline{\mu}d - k\Lambda) + \delta\big[(1-\overline{\mu})\mathcal{V}^p_{SCR} + \overline{\mu}V^p_{SCR}(C|\,1)\big] \\
V^p_{SCR}(C|\,1) &= (1-\delta)(\overline{\mu}d - l - k\Lambda) + \delta\big[(1-\overline{\mu})\mathcal{V}^p_{SCR} + \overline{\mu}V^p_{SCR}(C|\,1)\big] \\
V^p_{SCR}(PnSR) &= (1-\delta)(\overline{\mu}d) + \delta\mathcal{V}^p_{SCR} \\
V^p_{SCR}(PSR) &= (1-\delta)(\bar{\phi}(1-\underline{\gamma})R\Lambda + \underline{\mu}d) + \delta\big[(1-\underline{\mu})(1-\underline{\gamma})\mathcal{V}^p_{SCR} \\
&\quad + (1-\underline{\mu})\underline{\gamma}V^p_{SCR}(C|\,0) + \underline{\mu}V^p_{SCR}(C|\,1)\big]
\end{aligned} \tag{3}
$$

where

$$
\mathcal{V}^p_{SCR} \equiv \theta V^p_{SCR}(PSR) + (1-\theta)V^p_{SCR}(PnSR)
$$

is the expected value of continuing to a peaceful automaton state. Similarly, we let $V^\ell(C|\,s,\omega)$ denote the value of the traders in the *Conflict* state when $(s,\omega) \in \{0,1\}\times\{0,1\}$, and $V^\ell(PnSR)$ and $V^\ell(PSR)$ their values in the *Peace and no Self Regulation* and *Peace and Self Regulation* states respectively. These value functions satisfy the following recursive system of equations:

$$
\begin{aligned}
V^\ell_{SCR}(C|\,0,0) &= (1-\delta)(-k/\Lambda) + \delta\big[(1-\overline{\mu})\mathcal{V}^\ell_{SCR}(P) + \overline{\mu}\mathcal{V}^\ell_{SCR}(C|\,1)\big] \\
V^\ell_{SCR}(C|\,0,1) &= (1-\delta)(g - k/\Lambda) + \delta\big[(1-\overline{\mu})\mathcal{V}^\ell_{SCR}(P) + \overline{\mu}\mathcal{V}^\ell_{SCR}(C|\,1)\big] \\
V^\ell_{SCR}(C|\,1,1) &= (1-\delta)\big[(1-\overline{\gamma})R + g - k/\Lambda\big] + \delta\big[(1-\overline{\mu})\mathcal{V}^\ell_{SCR}(P) + \overline{\mu}\mathcal{V}^\ell_{SCR}(C|\,1)\big] \\
V^\ell_{SCR}(C|\,1,0) &= (1-\delta)\big[(1-\overline{\gamma})R - k/\Lambda\big] + \delta\big[(1-\overline{\mu})\mathcal{V}^\ell_{SCR}(P) + \overline{\mu}\mathcal{V}^\ell_{SCR}(C|\,1)\big] \\
V^\ell_{SCR}(PnSR) &= (1-\delta)(0) + \delta\mathcal{V}^\ell_{SCR}(P) \\
V^\ell_{SCR}(PSR) &= (1-\delta)\big[(1-\bar{\phi})(1-\underline{\gamma})R\big] + \delta\big[(1-\underline{\mu})(1-\underline{\gamma})\mathcal{V}^\ell_{SCR}(P) \\
&\quad + (1-\underline{\mu})\underline{\gamma}\mathcal{V}^\ell_{SCR}(C|\,0) + \underline{\mu}\mathcal{V}^\ell_{SCR}(C|\,1)\big]
\end{aligned} \tag{4}
$$

where

$$
\begin{aligned}
\mathcal{V}^\ell_{SCR}(P) &\equiv \theta V^\ell_{SCR}(PSR) + (1-\theta)V^\ell_{SCR}(PnSR) \\
\mathcal{V}^\ell_{SCR}(C|\,1) &\equiv \theta V^\ell_{SCR}(C|\,1,1) + (1-\theta)V^\ell_{SCR}(C|\,0,1) \\
\mathcal{V}^\ell_{SCR}(C|\,0) &\equiv \theta V^\ell_{SCR}(C|\,1,0) + (1-\theta)V^\ell_{SCR}(C|\,0,0)
\end{aligned}
$$

are the expected values of continuing to a peaceful automaton state and a conflictual automaton state with $\omega = 1$ and $\omega = 0$, respectively.

SCR[SR] payoffs The systems of recursive value functions for the SCR[SR] are the same as above but with

$$\begin{aligned} V^p_{SCR}(C|\ 0) &= (1-\delta)(\underline{\mu}d - k\Lambda) + \delta\big[(1-\underline{\mu})\mathcal{V}^p_{SCR} + \underline{\mu}V^p_{SCR}(C|\ 1)\big] \\ V^p_{SCR}(C|\ 1) &= (1-\delta)(\underline{\mu}d - l - k\Lambda) + \delta\big[(1-\underline{\mu})\mathcal{V}^p_{SCR} + \underline{\mu}V^p_{SCR}(C|\ 1)\big] \end{aligned} \tag{5}$$

replacing the first two lines of (3), and

$$\begin{aligned} V^\ell_{SCR}(C|\ 0,0) &= (1-\delta)(-k/\Lambda) + \delta\big[(1-\underline{\mu})\mathcal{V}^\ell_{SCR}(P) + \underline{\mu}\mathcal{V}^\ell_{SCR}(C|\ 1)\big] \\ V^\ell_{SCR}(C|\ 0,1) &= (1-\delta)(g - k/\Lambda) + \delta\big[(1-\underline{\mu})\mathcal{V}^\ell_{SCR}(P) + \underline{\mu}\mathcal{V}^\ell_{SCR}(C|\ 1)\big] \\ V^\ell_{SCR}(C|\ 1,1) &= (1-\delta)\big[(1-\underline{\gamma})R + g - k/\Lambda\big] + \delta\big[(1-\underline{\mu})\mathcal{V}^\ell_{SCR}(P) + \underline{\mu}\mathcal{V}^\ell_{SCR}(C|\ 1)\big] \\ V^\ell_{SCR}(C|\ 1,0) &= (1-\delta)\big[(1-\underline{\gamma})R - k/\Lambda\big] + \delta\big[(1-\underline{\mu})\mathcal{V}^\ell_{SCR}(P) + \underline{\mu}\mathcal{V}^\ell_{SCR}(C|\ 1)\big] \end{aligned} \tag{6}$$

replacing the first four lines of (4).

3.8.2 Proof of Part 1

Note that under the NCR we have $\phi_t = 0$ in every period t in which society is not in a *Conflict* state, as assumed in the main text. Consider a strategy profile in which the players play according to the NCR after every possible history of play. We claim that this strategy profile is a PPE. It is clear that the trading group has no profitable deviations: this follows from assumption (A1). It is also clear that if the players are sufficiently myopic (δ is equal to or close to 0) the strategy profile is a PPE. For higher values of δ, however, this need not be the case since the pirates may want to deviate from the *Peace and no Self Regulation* state or from the *Conflict* states to lower their next period probability of entering the *Conflict* states. These deviations would entail switching from no self-regulation to self-regulation.

To find conditions under which such one-time deviations are not profitable, we first compute the value functions of the pirates at each of the states. The solution to (1) is

$$V^p_{NCR}(PnSR) = \overline{\mu}d - \delta\overline{\mu}(l + k\Lambda) \tag{7}$$

$$V^p_{NCR}(C) = \overline{\mu}d - (1 - \delta(1-\overline{\mu}))(l + k\Lambda) \tag{8}$$

The pirates' payoff to a one-time deviation from the automaton state $S \in \{PnSR, C\}$ is

$$V^p_{dev}(S) = (1-\delta)v^p_{dev}(S) + \delta\big[(1-\underline{\mu})V^p(PnSR) + \underline{\mu}V^p(C)\big] \tag{9}$$

where $v^p_{dev}(PnSR) = \underline{\mu}d$ and $v^p_{dev}(C) = \underline{\mu}d - l - k\Lambda$. Such deviations are unprofitable if $V^p_{dev}(S) \leq V^p(S)$ for $S \in \{PnSR, C\}$, or in other words

$$v^p_{dev}(S) \leq \frac{1}{1-\delta}\Big[V^p(S) - \delta\big[(1-\underline{\mu})V^p(PnSR) + \underline{\mu}V^p(C)\big]\Big],\ S \in \{PnSR, C\} \tag{10}$$

which follows from substituting (9) and rearranging. Substituting the values of $V^p(PnSR)$ and $V^p(C)$ from (7) and (8) into (10) and then taking the derivative of the right hand side of the inequality with respect to δ yields $-(\overline{\mu} - \underline{\mu})(l + k\Lambda)$ for both states S. Thus the right hand side of (10) is decreasing in δ for both states. This implies that if the inequality holds when δ goes to 1 then the NCR is supported by the PPE for all values of δ.

Substituting $v^p_{dev}(S)$ and the values from (7) and (8) into (10), taking δ to 1 on the right hand side, and then rearranging the inequalities for both $S \in \{PnSR, C\}$ yields the same inequality for both states: $(\overline{\mu} - \underline{\mu})(d - l - k\Lambda) \geq 0$. This is satisfied by assumption (A2), which states that $d - l - k\Lambda > 0$. Therefore, deviating at either state is unprofitable.

3.8.3 Candidates for f_C, f_{SR} and f_{nSR} (and Proof of Part 2(iii))

Let

$$f_C = \big[1 - (1-\theta)\overline{\mu} + \theta\underline{\gamma}(1-\underline{\mu})\big]d - \big[1 + \theta\underline{\gamma}(1-\underline{\mu})\big]l - k\Lambda - \theta\bar{\phi}(1-\underline{\gamma})R\Lambda \tag{11}$$

Define

$$\mu[a] = \begin{cases} \overline{\mu} & \text{if } a = nSR \\ \underline{\mu} & \text{if } a = SR \end{cases}$$

and for $a \in \{nSR, SR\}$ define a vector of payoffs $\mathbf{v}[a]$ by

$$\mathbf{v}[a] = \begin{pmatrix} v^{PSR}[a] \\ v^{PnSR}[a] \\ v^{C|1}[a] \\ v^{C|0}[a] \\ v^{dev}[a] \end{pmatrix} = \begin{pmatrix} \underline{\mu}d + \bar{\phi}(1-\underline{\gamma})R\Lambda \\ \overline{\mu}d \\ \mu[a]d - l - k\Lambda \\ \mu[a]d - k\Lambda \\ \overline{\mu}d + \bar{\phi}(1-\overline{\gamma})R\Lambda \end{pmatrix}$$

Similarly, define a vector of weights $\mathbf{w}[a] = \big(w^{PSR}[a], w^{PnSR}[a], w^{C|1}[a], w^{C|0}[a], w^{dev}[a]\big)$ by

$$\begin{aligned} w^{PSR}[a] &= 1 - \mu[a] + \theta[\overline{\mu} + \overline{\gamma}(1-\overline{\mu})] \\ w^{PnSR}[a] &= (1-\theta)\big[(\overline{\mu} + \overline{\gamma}(1-\overline{\mu})) - (\underline{\mu} + \underline{\gamma}(1-\underline{\mu}))\big] \\ w^{C|1}[a] &= -(\overline{\mu} - \underline{\mu}) - \mu[a]\big[\overline{\gamma}(1-\overline{\mu}) - \underline{\gamma}(1-\underline{\mu})\big] - \theta\big[\overline{\mu}\underline{\gamma}(1-\underline{\mu}) - \underline{\mu}\overline{\gamma}(1-\overline{\mu})\big] \\ w^{C|0}[a] &= -(1-\mu[a])\big[\overline{\gamma}(1-\overline{\mu}) - \underline{\gamma}(1-\underline{\mu})\big] + \theta\big[\overline{\mu}\underline{\gamma}(1-\underline{\mu}) - \underline{\mu}\overline{\gamma}(1-\overline{\mu})\big] \\ w^{dev}[a] &= -\big[1 - \mu[a] + \theta(\underline{\mu} + \underline{\gamma}(1-\underline{\mu}))\big] \end{aligned}$$

We then define the functions f_{SR} and f_{nSR} by

$$f_{SR} = \mathbf{w}[SR] \cdot \mathbf{v}[SR] \qquad \text{and} \qquad f_{nSR} = \mathbf{w}[nSR] \cdot \mathbf{v}[nSR] \tag{12}$$

We show below that for both $a = nSR, SR$, the weighted average of flow payoffs represented in vector $\mathbf{v}[a]$ where weights are given by $\mathbf{w}[a]$ must be positive for the pirates to have no profitable deviation at the *Peace and Self Regulation* state. Note that the components of the vector of weights $\mathbf{w}[a]$ sum to 1 for each $a = nSR, SR$. Moreover, for both $a = nSR, SR$ the weight $w^{dev}[a]$ is negative meaning that as the flow payoff from one time deviation becomes more attractive, it is harder to support the path automaton in equilibrium.

Second, note that in the product $\mathbf{w}[a] \cdot \mathbf{v}[a]$, $a = nSR, SR$, the parameter $\bar{\phi}$ appears only in a product with $R\Lambda$ and the parameter Λ appears either as a product with $\bar{\phi}R$ or with k. The coefficient of $k\Lambda$ in $\mathbf{w}[a] \cdot \mathbf{v}[a]$ is $-(w^{C|1}[a] + w^{C|0}[a])$, which is positive for both $a = nSR, SR$. The coefficient of the term $\bar{\phi}R\Lambda$ in the product $\mathbf{w}[a] \cdot \mathbf{v}[a]$ is $(1-\underline{\gamma})w^{PSR}[a] - (1-\overline{\gamma})w^{dev}[a]$, which is also positive for both $a = nSR, SR$. Therefore $\mathbf{w}[a] \cdot \mathbf{v}[a]$ is increasing in Λ and $\bar{\phi}$ for both $a = nSR, SR$.

Finally, the coefficient of d in $\mathbf{w}[a] \cdot \mathbf{v}[a]$ is negative for both $a = nSR, SR$ so when d increases it is harder to provide incentives to the pirates to not deviate from the *Peace and Self Regulation* state on the path of play of either $SCR[nSR]$ or $SCR[SR]$.

These observations establish the comparative statics reported in part 2(iii) of the proposition. We now prove the remainder.

3.8.4 Proof of Part 2(i)

Consider a PPE under which the players play according to the SCR[nSR] and any deviation by livestock traders is met by switching to the NCR forever after. As is well-known, the payoff for each group $i = \ell, p$ in the limit as $\delta \to 1$ is the same across all automaton states and equals a weighted average of flow payoffs for each state with weights being the corresponding components of the stationary distribution of the Markov process governing automaton state transitions. Let $V^{\ell*}_{NCR}$ denote this limiting value for the traders respectively in the NCR and $V^{\ell*}_{SCR}$ the limiting values the traders in the SCR[nSR]. Since the NCR can be supported in equilibrium for all values of the discount factor, the livestock traders have no profitable one-time deviations for all high enough values of δ if and only if $V^{\ell*}_{SCR} - V^{\ell*}_{NCR} > 0$. To show that this holds, we compute that for a positive constant $\zeta := [1 - \overline{\mu} + \theta\underline{\mu} + \underline{\gamma}\theta(1-\underline{\mu})]/(1-\overline{\mu})$

$$\begin{aligned}\frac{1}{\zeta}(V^{\ell*}_{SCR} - V^{\ell*}_{NCR}) &= \theta[(1-\bar{\phi})(1-\underline{\gamma})R - (1-\overline{\gamma})R] - (\overline{\mu} - \theta\underline{\mu})(g - k/\Lambda) - \underline{\gamma}\theta(1-\underline{\mu})(k/\Lambda) \\ &\geq \theta\left[(1-\bar{\phi})(1-\underline{\gamma})R - \left(1 + \frac{1}{1-\underline{\mu}}\right)(1-\overline{\gamma})R\right] - [1 + \underline{\gamma}(1-\underline{\mu})\theta]g - k/\Lambda > 0\end{aligned}$$

where the first inequality follows because $g - k/\Lambda > 0$ by (A1) and the second inequality follows from assumption (A3). Therefore, it is sufficient for us to examine only the no profitable one-time deviation condition for the pirates.

The solution to the recursive system of equations in (3) is unique and follows from straightforward algebra. To save space, we do not report it. In what follows we consider one-time deviations by the pirates from the two *Conflict* states, the *Peace and Self Regulation* state and the *Peace and no Self Regulation* state, characterizing conditions under which these one-time deviations are unprofitable.

1. We start by showing that when δ is high, the pirates have no incentive to deviate from the *Conflict* state when $\omega_t = \omega$. If the pirates deviate from this state, then with probability $\underline{\mu}$ we have $\omega_{t+1} = 1$ and society returns to a *Conflict* state with $\omega_{t+1} = 1$. With probability $1 - \underline{\mu}$ society exits the *Conflict* states, entering the *Peace and Self Regulation* state with probability θ and the *Peace and no Self Regulation* with probability $1 - \theta$. Thus, the deviation is unprofitable if and only if

$$v^p_{dev}(C|\ \omega) \leq \frac{1}{1-\delta}\Big[V^p_{SCR}(C|\ \omega) - \delta\big[(1-\underline{\mu})\mathcal{V}^p_{SCR} + \underline{\mu}V^p_{SCR}(C|\ 1)\big]\Big]$$

for $\omega \in \{0, 1\}$, where $v^p_{dev}(C|\ 0) = \underline{\mu}d - k\Lambda$ and $v^p_{dev}(C|\ 1) = \underline{\mu}d - l - k\Lambda$. Substituting the values of $V^p_{SCR}(C|\ \omega)$ and $V^p_{SCR}(PSR)$ solved from the system above, and the value of $v^p_{dev}(C|\ \omega)$, rearranging and taking $\delta \to 1$ yields the same inequality for both values of $\omega \in \{0, 1\}$. The inequality is

$$\frac{\overline{\mu} - \underline{\mu}}{1 - \overline{\mu} + \theta\left(\underline{\mu} + \underline{\gamma}(1-\underline{\mu})\right)}\Big(\big[1-(1-\theta)\overline{\mu}+\theta\underline{\gamma}(1-\underline{\mu})\big]d - \big[1+\theta\underline{\gamma}(1-\underline{\mu})\big]l - k\Lambda - \theta\bar{\phi}(1-\underline{\gamma})R\Lambda\Big) \geq 0$$

Since the coefficient of the term in large square brackets is positive, the term in large square brackets must be positive to guarantee no profitable deviations for all high values of δ. This gives the inequality $f_C > 0$ where f_C is defined in (11). Since this inequality is satisfied by assumption, one-time deviations from either of the *Conflict* states are unprofitable.

2. Now consider a deviation for the pirates from the *Peace and Self Regulation* state. The deviation yields an instantaneous expected payoff of $\overline{\mu}d + \bar{\phi}(1-\overline{\gamma})R\Lambda$. After the deviation, the players enter the *Conflict* state with $\omega_t = 1$ with probability $\overline{\mu}$, the *Conflict* state with $\omega_t = 0$ with probability $\overline{\gamma}(1-\overline{\mu})$ and they exit the *Conflict* states entering the *Peace and Self Regulation* state with probability $(1-\overline{\mu})(1-\overline{\gamma})\theta$ and the *Peace and no Self Regulation* state with probability $(1-\overline{\mu})(1-\overline{\gamma})(1-\theta)$. Therefore, the deviation is

unprofitable if and only if

$$\overline{\mu}d + \bar{\phi}(1-\overline{\gamma})R\Lambda \leq \frac{1}{1-\delta}\Big[V^p_{SCR}(PSR) - \delta\big[(1-\overline{\gamma})(1-\overline{\mu})\mathcal{V}^p_{SCR} + \overline{\gamma}(1-\overline{\mu})V^p_{SCR}(C|\,0) + \overline{\mu}V^p_{SCR}(C|\,1)\big]\Big]$$

Substituting $V^p_{SCR}(PSR)$, $\mathcal{V}^p_{SCR}$, $V^p_{SCR}(C|\,0)$, and $V^p_{SCR}(C|\,1)$ solved from the system of recursive equations, taking the limit as $\delta \to 1$, and rearranging yields

$$\frac{1}{1-\overline{\mu}+\theta\left(\underline{\mu}+\underline{\gamma}(1-\underline{\mu})\right)}\left(\mathbf{w}[nSR]\cdot\mathbf{v}[nSR]\right) \geq 0$$

where $\mathbf{w}[nSR]$ and $\mathbf{v}[nSR]$ are the vectors defined in Section C. Since the coefficient of the product of these vectors is positive, the product of vectors must be positive to guarantee no profitable deviations for all high values of δ. This gives the inequality $f_{SR} > 0$ where f_{SR} is given by (12).

3. If the pirates do not deviate at the *Peace and no Self Regulation* state, then they receive $V^p_{SCR}(PnSR) = (1-\delta)(\overline{\mu}d) + \delta\mathcal{V}^p_{SCR}$ but if they do deviate then they receive only $(1-\delta)(\underline{\mu}d) + \delta\mathcal{V}^p_{SCR}$. Therefore, the deviation is not profitable.

3.8.5 Proof of Part 2(ii)

This time let $V^{\ell *}_{SCR}$ denote the the limiting payoff of the livestock traders in the SCR[SR]. These traders have no profitable one time deviation for all high values of δ if and only if $V^{\ell *}_{SCR} - V^{\ell *}_{NCR} > 0$. We compute, as before, that for a positive constant $\xi := [1-\underline{\mu}+\theta\underline{\mu}+\underline{\gamma}\theta(1-\underline{\mu})]/(1-\underline{\mu})$

$$\begin{aligned}\frac{1}{\xi}(V^{\ell *}_{SCR} - V^{\ell *}_{NCR}) &= \theta\left[\left(\xi-\bar{\phi}\right)(1-\underline{\gamma})R - \xi(1-\overline{\gamma})R\right] - [1+\underline{\gamma}\theta(1-\underline{\mu})]g - k/\Lambda \\ &\geq \theta\left[(1-\bar{\phi})(1-\underline{\gamma})R - \left(1+\frac{1}{1-\underline{\mu}}\right)(1-\overline{\gamma})R\right] - [1+\underline{\gamma}(1-\underline{\mu})\theta]g - k/\Lambda > 0\end{aligned}$$

where the first inequality follows because $1+\frac{1}{1-\underline{\mu}} > \xi > 1$ and the second inequality follows from assumption (A3). Therefore, it is sufficient for us to examine only the no profitable one-time deviation condition for the pirates.

As before, the solution to the recursive system of equations defining the pirates payoffs in the SCR[SR] is unique, and again we do not report it to save space. We consider one-time deviations by the pirates from the two *Conflict* states, the *Peace and Self Regulation* state and the *Peace and no Self Regulation* state, characterizing conditions under which these one-time deviations are unprofitable.

1. If the pirates deviate from a *Conflict* state, then with probability $\overline{\mu}$ we have $\omega_{t+1} = 1$ and society returns to a *Conflict* state with $\omega_{t+1} = 1$. With probability $1 - \overline{\mu}$ society exits the *Conflict* states, entering a *Peace and Self Regulation* state with probability θ and a *Peace and no Self Regulation* with probability $1 - \theta$. Thus, the deviation is unprofitable if and only if

$$v^p_{dev}(C|\,\omega) \leq \frac{1}{1-\delta}\Big[V^p_{SCR}(C|\,\omega) - \delta\big[(1-\overline{\mu})\mathcal{V}^p_{SCR} + \overline{\mu}V^p(C|\,1)\big]\Big]$$

for $\omega \in \{0, 1\}$, where $v^p_{dev}(C|\,0) = \overline{\mu}d - k\Lambda$ and $v^p_{dev}(C|\,1) = \overline{\mu}d - l - k\Lambda$. Substituting the values of $V^p_{SCR}(C|\,\omega)$ and $V^p_{SCR}(PSR)$ solved from the system above, and the value of $v^p_{dev}(C|\,\omega)$, rearranging and taking $\delta \to 1$ yields the same inequality for both values of $\omega \in \{0, 1\}$. The inequality is

$$\frac{\overline{\mu}-\underline{\mu}}{1-\underline{\mu}+\theta\left(\underline{\mu}+\underline{\gamma}(1-\underline{\mu})\right)}\Big(\big[1-(1-\theta)\overline{\mu}+\theta\underline{\gamma}(1-\underline{\mu})\big]d-\big[1+\theta\underline{\gamma}(1-\underline{\mu})\big]l-k\Lambda-\theta\bar{\phi}(1-\underline{\gamma})R\Lambda\Big) \leq 0$$

Since the coefficient of the term in large square brackets is positive, the term in large square brackets must be negative to guarantee no profitable deviations for all high values of δ. This produces $f_C < 0$.

2. Now consider a deviation for the pirates from the *Peace and Self Regulation* state. The deviation yields an instantaneous expected payoff of $\overline{\mu}d+\bar{\phi}(1-\overline{\gamma})R\Lambda$. After the deviation, the players enter the *Conflict* state with $\omega_t = 1$ with probability $\overline{\mu}$, the *Conflict* state with $\omega_t = 0$ with probability $\overline{\gamma}(1-\overline{\mu})$ and they exit the *Conflict* states entering a *Peace and Self Regulation* state with probability $(1-\overline{\mu})(1-\overline{\gamma})\theta$ and a *Peace and no Self Regulation* state with probability $(1-\overline{\mu})(1-\overline{\gamma})(1-\theta)$. Therefore, the deviation is unprofitable if and only if

$$\overline{\mu}d + \bar{\phi}(1-\overline{\gamma})R\Lambda \leq \frac{1}{1-\delta}\Big[V^p_{SCR}(PSR) - \delta\big[(1-\overline{\gamma})(1-\overline{\mu})\mathcal{V}^p_{SCR} + \overline{\gamma}(1-\overline{\mu})V^p_{SCR}(C|\,0) + \overline{\mu}V^p_{SCR}(C|\,1)\big]\Big]$$

Substituting $V^p_{SCR}(PSR)$, $\mathcal{V}^p_{SCR}$, $V^p_{SCR}(C|\,0)$, and $V^p_{SCR}(C|\,1)$ solved from the system of recursive equations above, taking the limit as $\delta \to 1$, and rearranging yields

$$\frac{1}{1-\underline{\mu}+\theta\left(\underline{\mu}+\underline{\gamma}(1-\underline{\mu})\right)}\left(\mathbf{w}[SR]\cdot\mathbf{v}[SR]\right) \geq 0$$

where $\mathbf{w}[SR]$ and $\mathbf{v}[SR]$ are the vectors defined in the statement of the proposition. Since the coefficient of the product of these vectors is positive, the product of vectors must be positive to guarantee no profitable deviations for all high values of δ. This produces the inequality $f_{SR} > 0$.

3. Finally, if the pirates do not deviate at a *Peace and no Self Regulation* state, then they receive $V^p_{SCR}(PnSR) = (1-\delta)(\overline{\mu}d) + \delta\mathcal{V}^p_{SCR}$ but if they do deviate then they receive only $(1-\delta)(\underline{\mu}d) + \delta\mathcal{V}^p_{SCR}$. Therefore, the deviation is not profitable.

$\square$

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