Does Criminal Violence Spread? Contagion and Counter-contagion Mechanisms of Piracy

Jessica Di Salvatore
University of Warwick
Jessica.di-salvatore@warwick.ac.uk

APPENDIX

Table A.I. ZINB with Month Fixed Effects

	Model with Month Fixed-Effects	
Variables	ZINB	Inflation stage
Reinforcement	1.182***	
	(0.317)	
Contiguity(t-1)	1.941***	
	(0.707)	
Contiguity	0.563***	
	(0.0786)	
Rate of Success(t-1)	0.975***	
	(0.110)	
Density	0.0244**	-1.633***
	(0.0121)	(0.417)
Density (sq)	-0.000260**	
	(0.000103)	
Distance port	-0.191***	
	(0.0388)	
Distance port (sq)	0.000756	
	(0.00153)	
Distance chokepoint	0.000367	
	(0.000294)	
Killed	5.361***	
	(0.924)	
Killed (sq)	-2.618***	
	(0.459)	
Constant	-5.165***	0.604***
	(0.250)	(0.210)

Clustered standard errors
*** p<0.01, ** p<0.05, * p<0.1

Table A.II. ZINB Models with Diffusion variables separately

Variables	(1) Reinforcement only	(2) Inflation stage	(3) Contagion only	(4) Inflation stage	(5) Learning only	(6) Inflation stage
Density	0.0286**	-1.626***	0.0273**	-1.612***	0.0270**	-1.556***
	(0.0122)	(0.428)	(0.0136)	(0.458)	(0.0121)	(0.450)
Density (sq)	-0.000338*		-0.000279**		-0.000317*	
	(0.000183)		(0.000109)		(0.000167)	
Distance port	-0.218***		-0.201***		-0.222***	
	(0.0378)		(0.0432)		(0.0382)	
Distance port (sq)	0.00219		0.000914		0.00245	
	(0.00151)		(0.00161)		(0.00151)	
Summer Monsoon	-0.607***		-0.575***		-0.547***	
	(0.115)		(0.123)		(0.123)	
Distance chokepoint	0.000256		0.000393		0.000258	
	(0.000279)		(0.000339)		(0.000285)	
Killed	3.948***		3.112***		3.778***	
	(0.571)		(0.632)		(0.607)	
Killed (sq)	-1.904***		-1.492***		-1.818***	
	(0.284)		(0.314)		(0.302)	
Contiguity			1.216***			
			(0.109)			
Contiguity $(t-1)$			0.832***			
			(0.0786)			
Reinforcement	2.481***					
	(0.137)					
Rate of Success$(t-1)$					5.870***	
					(0.282)	
Constant	-4.791***	0.797***	-5.113***	0.619***	-4.788***	0.819***
	(0.209)	(0.205)	(0.263)	(0.215)	(0.217)	(0.198)
lnalpha		1.835***		2.171***		1.785***
		(0.195)		(0.210)		(0.268)
Observations	320,112	320,112	320,112	320,112	320,112	320,112

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.III. ZINB with main IVs' lags and leads.

Variables	ZINB	Inflation stage
Reinforcement	0.505***	
	(0.148)	
Contiguity	-0.0948	
	(0.0915)	
Contiguity (t-1)	0.0546	
	(0.0702)	
Rate of Success(t-1)	15.71***	
	(0.558)	
Rate of Success (t+1)	0.532	
	(0.387)	
Contiguity (t+1)	-0.0665	
	(0.0430)	
Density	0.000183	-1.432***
	(0.00932)	(0.125)
Density (sq)	-0.000132	
	(0.000210)	
Distance port	-0.0413***	
	(0.0154)	
Distance port (sq)	0.00114*	
	(0.000659)	
Distance chokepoint	-0.0951	
	(0.139)	
Summer Monsoon	-2.21e-05	
	(9.81e-05)	
Killed	-8.044	
	(6.440)	
Killed (sq)	3.956	
	(3.170)	
Constant	-7.013***	-17.13***
	(0.615)	(0.114)

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.IV. ZINB Models with Successful Piracy Attacks only

Variables	(1) Successful attacks	(2) Inflation stage	(3) Successful attacks	(4) Inflation stage
Density	0.0312	-2.339***	0.0334	-2.370***
	(0.0244)	(0.580)	(0.0241)	(0.577)
Density (sq)	-0.000198		-0.000221	
	(0.000156)		(0.000154)	
Distance port	-0.313***		-0.308***	
	(0.0626)		(0.0632)	
Distance port (sq)	0.00182		0.00177	
	(0.00257)		(0.00257)	
Summer Monsoon	-0.733***		-0.757***	
	(0.171)		(0.172)	
Distance chokepoint	0.00128***		0.00120**	
	(0.000492)		(0.000498)	
Killed	2.536*		2.561*	
	(1.317)		(1.373)	
Killed (sq)	-1.245*		-1.254*	
	(0.655)		(0.683)	
Reinforcement	0.618**		2.418***	
	(0.281)		(0.350)	
Rate of Success$(t-1)$	4.651***			
	(0.510)			
Contiguity$(t-1)$	0.538***		0.813***	
	(0.126)		(0.191)	
Contiguity	0.910***		1.047***	
	(0.123)		(0.156)	
Constant	-6.537***	0.989***	-6.489***	0.963***
	(0.398)	(0.339)	(0.380)	(0.346)
lnalpha		2.324***		2.855***
		(0.442)		(0.499)
Observations	320,112	320,112	320,112	320,112

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.V. ZINB Models with Transition Corridor dummy

Variables	(1) Corridor Diffusion	(2) Inflation stage	(4) Corridor Counter-diffusion	(5) Inflation stage
Density	0.0180	-1.668***	0.00679	-1.478***
	(0.0140)	(0.400)	(0.0116)	(0.420)
Density (sq)	-0.000175**		-0.000156	
	(7.82e-05)		(0.000108)	
Distance port	-0.186***		-0.0839**	
	(0.0398)		(0.0359)	
Distance port (sq)	0.000343		-0.00232	
	(0.00158)		(0.00178)	
Summer Monsoon	-0.542***		-0.858***	
	(0.116)		(0.163)	
Distance chokepoint	0.000440		0.000299	
	(0.000308)		(0.000226)	
Killed	2.779***		12.26	
	(0.770)		(7.727)	
Killed (sq)	-1.437***		-6.096	
	(0.385)		(3.801)	
Reinforcement	1.153***		1.641***	
	(0.313)		(0.371)	
Rate of Success$(t-1)$	1.803***		1.409	
	(0.689)		(0.987)	
Contiguity$(t-1)$	0.497***		0.368***	
	(0.0750)		(0.0812)	
Contiguity	0.969***		0.850***	
	(0.119)		(0.131)	
IRTC	0.853***		1.009***	
	(0.207)		(0.249)	
Rescue$(t-1)$			-1.031**	
			(0.476)	
Rescue$(t-2)$			1.429***	
			(0.264)	
Rescue$(t-3)$			1.369***	
			(0.218)	
Atlanta	1.006***			
	(0.268)			
Constant	-5.234***	0.577***	-5.262***	0.573***
	(0.255)	(0.215)	(0.747)	(0.212)
lnalpha		1.595***		1.356***
		(0.220)		(0.319)
Observations	320,112	320,112	177,840	177,840

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.VI. ZINB Models with data aggregated by quarter.

Variables	(1) Quarterly Diffusion	(2) Inflation stage	(3) Quarterly Counterdiffusion	(4) Inflation stage
Density	0.0311***	-2.722***	0.0324***	-1.925***
	(0.00970)	(0.369)	(0.0105)	(0.262)
Density (sq)	-0.000526**		-0.000524**	
	(0.000214)		(0.000214)	
Distance port	-0.0881***		-0.0784***	
	(0.0224)		(0.0238)	
Distance port (sq)	-0.000520		-0.000931	
	(0.00109)		(0.00120)	
Summer Monsoon	-0.360***		-0.263***	
	(0.0840)		(0.0840)	
Distance chokepoint	0.000125		2.67e-05	
	(0.000118)		(0.000127)	
Killed	0.153***		0.211***	
	(0.0300)		(0.0313)	
Killed (sq)	-0.00789***		-0.0104***	
	(0.00208)		(0.00198)	
Reinforcement	0.830**		1.091***	
	(0.386)		(0.337)	
Rate of Success$_{(t-1)}$	23.62***		24.36***	
	(2.299)		(2.013)	
Contiguity$_{(t-1)}$	-1.059**		-0.926**	
	(0.448)		(0.430)	
Contiguity	1.202**		1.104**	
	(0.479)		(0.456)	
Rescue$_{(t-1)}$			-0.295	
			(0.247)	
Rescue$_{(t-2)}$			-0.0886	
			(0.131)	
Rescue$_{(t-3)}$			-1.509***	
			(0.248)	
Constant	-5.585***	-17.65***	-5.764***	-16.97***
	(0.141)	(0.252)	(0.163)	(0.222)
lnalpha		0.248**		0.104
		(0.0974)		(0.0927)
Observations	106,704	106,704	106,704	106,704

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.VII. ZINB Models with Diffusion covariates at 4 months lag

Variables	(1) 4 Months Lag	(2) Inflation Stage
Density	0.0246**	-1.589***
	(0.0114)	(0.421)
Density (sq)	-0.000294*	
	(0.000152)	
Distance port	-0.202***	
	(0.0385)	
Distance port (sq)	0.00156	
	(0.00153)	
Summer Monsoon	-0.609***	
	(0.134)	
Distance chokepoint	0.000289	
	(0.000275)	
Killed	3.576***	
	(0.559)	
Killed (sq)	-1.733***	
	(0.279)	
Reinforcement $(t-4)$	1.527***	
	(0.207)	
Rate of Success $(t-4)$	3.230***	
	(0.482)	
Contiguity$(t-5)$	0.544***	
	(0.0872)	
Contiguity $t-4$	0.526***	
	(0.0809)	
Constant	-4.835***	0.723***
	(0.218)	(0.199)
lnalpha		2.106***
		(0.227)
Observations	308,256	308,256

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Markov-Chain Logit

The first column in Table A. VIII shows the likelihood that piracy will occur in a locations that has not experiences piracy at *t-1*, in other words it tests the spread of piracy to new locations. Column two in Table A. VIII shows the likelihood that piracy will occur again in locations that experienced attacks at *t-1*, thus testing the likelihood of repeated activity in a cell-month. First thing to highlight is that the spatial lags of piracy behave similarly in both models, indicating that cells contiguous to attacked locations are more likely to experience both diffusion *and* re-occurrence of piracy; to put it otherwise, they are at risk regardless of whether they have already experienced piracy in the previous month. However, it is noteworthy that previous successes lead to higher likelihood of spread to new, surrounding locations but lower likelihood of re-occurrence in previously targeted areas. This result is statistically significant only at 0.1 level, but it points out that successes also bear costs in terms of attracting EU counter-piracy attention. When pirates successfully board or hijack a vessel, they may prompt EU reaction and, in turn, are forced to move away from these areas. This means that success will reduce chances of repeated attacks in the following month, but increase odds of attacks in surrounding areas. Differently from the learning mechanisms, contiguity does not tell us about the success of attacks, which explains why occurrence of attacks in surrounding areas can still lead to both spread and reoccurrence as attempted attacks are less likely to draw attention and being reported.

While testing spread of piracy as a Markovian process may provide a more conservative test for the diffusion hypothesis, the underlying assumptions of Markov-Chain logit models may pose too many restrictions on the data generating process. For example, the Markovian logit assumes that all units have a probability of transitioning from no-piracy to piracy greater than 0, so it is not possible to account for the zeros inflation. Also the stationarity of the transition probabilities is debatable if we consider seasonal variation and, probably more important, the deployment of the EU navy as a structural shock.

Table A. VIII. Markov-Chain logit models

Variables	Transition from No Piracy → Piracy Diffusion of Piracy	Transition from Piracy → Piracy Recurrence of Piracy
Rate of Success $(t-1)$	6.815**	-3.921*
	(3.820)	(1.725)
Contiguity $(t-1)$	0.448***	0.454***
	(0.0717)	(0.165)
Contiguity	0.791***	0.743***
	(0.0931)	(0.161)
Density	0.0770***	0.0737*
	(0.0159)	(0.0426)
Density (sq)	-0.00102**	-0.000927
	(0.000472)	(0.000797)
Distance port	-0.173***	-0.139
	(0.0364)	(0.158)
Distance port (sq)	0.000775	0.000550
	(0.00152)	(0.00888)
Distance chokepoint	0.000291	0.000646
	(0.000264)	(0.000689)
Killed	2.434***	4.919**
	(0.702)	(2.366)
Killed (sq)	-1.148***	-2.529**
	(0.349)	(1.177)
Summer Monsoon	-0.698***	-0.146
	(0.113)	(0.313)
Constant	-5.838***	-1.068
	(0.195)	(0.925)
Observations	319,245	867

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Predicted Geography of Piracy Risk

It is also useful to look at how the risk of piracy varies in space, compared to where actual attacks occurs. Given the high number of units in the sample, it is difficult to compare predictions for each location over time. Alternatively, I present the average risk of piracy as estimated in the main models for the manuscript, namely the ZINB with diffusion variables and the ZINB with both diffusion and counter-diffusion variables. These are the same models whose ROC curves are compared at the end of the article. Figure A.I compares the risk of piracy as predicted by the diffusion-only model (left panel) and by the counter-diffusion model (right panel) with the actual density of piracy incidents shown in the manuscript (central panel) for the year 2005-2013. Both right and left panels show similar geographic patterns, although the right-hand map that includes EU counter-piracy efforts seems to be more precise at identifying high risk areas (darker red shades), which in turns provide a more accurate prediction compared to the actual risk areas. For example, according to the diffusion-only predictions, the whole Somali coastline is predicted to have extremely high risk of piracy also in areas where very few incidents occurred (e.g. north-west Somali basin). Accounting for factors that have reduced the incidence of piracy in some areas, however, only identifies few hotspots along the Somali coast, and even fewer within the Somali basin.

Figure A. I. Average Probability of Piracy Attacks by grid-cell