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Making space for crime: A spatial analysis of criminal competition ☆

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ABSTRACT

This paper utilizes a spatial competition model to analyze criminal activity. Criminals are heterogeneous in their cost of providing illegal goods and compete by choosing a location and a price for the distribution of the illegal goods to clients. The locational choice of criminals and law enforcement technology are permitted to interact and the spatial equilibrium of criminals is determined. A particularly striking finding is that an increase in law enforcement effort can increase the market share of criminals by forcing low productivity criminals out of the market, thereby allowing fewer criminals to serve the inelastic demands of the illegal goods market.

1. Introduction

The spatial distribution of crime has received considerable attention (see Glaeser et al. (1996), Freeman et al. (1996) and Zenou (2003)) and displays a trend that crime is concentrated in the poor city center instead of suburbs (see Verdier and Zenou (2004) and Glaeser and Sacerdote (1999)). The majority of this research focuses on the incentives for individuals to participate in criminal activities, such as pecuniary benefits, social interactions with other criminals, and access to criminal opportunities. However, the choice of where to commit crimes is often driven by other forces, such as a gang's turf (see Tita and Ridgeway (2007), Tita et al. (2005) and Ratcliffe and Taniguchi (2011)), barriers to committing a crime (e.g. gated communities—see Helsley and Strange (1999)), and law enforcement (see Ehrlich (1973), Levitt (1997), and DiTella and Schargrodsky (2004)). The interplay between criminal opportunities, the ability/efficiency of competitors, and the presence of law enforcement make the location and size of a criminal enterprise an interesting object of observation (Table 1).

Criminal organizations (such as gangs, mafias, etc.) control a share of the market and behave similarly to legitimate businesses in that they must be cognizant of competitors and the efficiency of their competitors in determining where to operate and what price to charge. The main difference between legitimate businesses and firms operating in the "black market" is that illegitimate businesses require protection in the form of violence in order to protect their turf (see Skaperdas (2001), Reuter (1983) and Donohue and Levitt (1998)), whereas legitimate firms can utilize the legal system for protection. Moreover, since a criminal organization's affairs are typically not legal (e.g. drug dealing), it must also concern itself with the presence of law enforcement in determining where to locate and how to operate. Given these forces, it is evident that the choice of where a criminal organization decides to locate, the size of its turf, the distance between organizations, and the price that the organization charges for an illegal good can be determined by several market factors. It is the aim of this paper to provide theoretical explanations for the role of differences in a criminal organization's productive efficiency, ability to defend turf, and the presence of law enforcement on the composition of the geographic black market—as defined by the number of criminal organizations, distance between organizations, and market share of each organization.

Fig. 1 provides four snapshots of African-American gang territories over time—see Alonso (1999) for a discussion of the data collection

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Table 1
Summary statistics of gang territories.

Year	Number of territories	Mean size (sq. mi.)	Variance (sq. mi.)	Total (sq. mi.)	Distance (miles)
1960	25	0.87	1.12	21.80	1.68
1972	18	1.67	1.18	29.98	1.40
1978	60	0.64	0.57	38.29	0.95
1996	241	0.26	0.36	62.33	0.92

methods.[1] From mere observation, it is evident that the number of gangs and the total gang turf have increased over time. Utilizing geographic information systems, summary statistics are provided about the physical features of the location and interplay of gangs.

The number of gangs and total territory coverage have increased as the average size of a territory as well as the variability in turf size have decreased over time. Stated differently, there has been a steady increase in the number of African-American gangs over time. However, the distribution of the size of gangs is becoming more tightly compact around a mean value that is decreasing over time.[2] Additionally, the distance between neighboring gangs has decreased by over a half mile in roughly 35 years. Over this same time period, steady increases in enforcement expenditures per capita in the cities that have African-American gangs residing in their boundaries have occurred—see Table 2.[3]

Although the relationship between the size of gang territories/ distance between neighboring gangs and enforcement expenditures per capita display an inverse relationship, there are many other factors that convolute the connection. The aim of this empirical discussion is not to determine causal relationship between the geographic composition of the black market and enforcement expenditures, but rather to emphasize that the composition of criminal organizations within the black market displays significant variation. It is the variation in the size, number, and distance between criminal organizations that is of primary interest in this analysis.

To examine the geographic variation in the black market this paper proposes a spatial competition model to analyze criminal activity. Criminals are heterogeneous in their cost of providing illegal goods and compete by choosing a location and a price for the distribution to clients. A law enforcement technology is available to prohibit the exchange of proscribed activities. Locational choice and law enforcement interact. The aim of this paper is to understand how changes in the production technology or law enforcement policies impact the structure—distance between and market share—of criminal organizations. For instance, how do changes in the production of illegal goods (e.g. introduction of crack cocaine) change the size of an organization's market share and the distance between an organization and its closest competitor? Moreover, traditional analyses of law enforcement do not account for spillover effects of enforcement on crime. This analysis addresses this problem directly by asking how law enforcement policies impact the size and distribution of criminal organizations. The use of criminal organizations as a unit of analysis is because the distance between and market share of criminal organizations is observable. Additionally, criminal organizations can be a nuisance to the area that they inhabit, resulting in the implementation of legislation to deal with the problems associated with these organizations, such as gang injunctions.[4] Moreover, the number of organizations has been on the rise (see Alonso (1999)). In that vein, an application of the spatial competition model—discussed in Vogel (2008)—is applied to criminal organization-related black market activities and the interplay between these organizations and law enforcement in order to produce policy conclusions that are relevant to illegal market activities.

2. Existing literature

Research in the area of law and economics typically looks at the theoretical and empirical impact of the price of crime (punishment, fines, jail sentence length, or apprehension probability) on market outcomes.[5] However, research has examined the variability in crime rates between urban/rural areas (see Glaeser et al. (1996), Cullen and Levitt (1999)), within cities (see Freeman et al. (1996), Glaeser and Sacerdote (1999), and Zenou (2003)), across ethnicities (see Verdier and Zenou (2004)), among socioeconomic backgrounds (see O'Flaherty and Sethi (2010) and Case and Katz (1991)), by age (see Bushway and DeAngelo (2011), Lee and McCrary (2010) and Levitt (1998)) and between sexes (see Freeman (1996) and Kling et al. (2005)). In short, this research displays higher crime rates within city boundaries, for poorer individuals, for ethnic minorities, for males and for youth offenders.

The role of space in the decision of where a criminal decides to locate plays a critical role in determining where crime will occur, the price of crime, the likelihood of violence among criminals and the effectiveness of law enforcement resources that are allocated to fight crime.[6] Zenou (2003) offers a succinct explanation for the variation in crime both within and across cities. Additionally, Freeman et al. (1996) show that crime will tend to concentrate in the neighborhood where the criminal has the lowest probability of being apprehended.[7] Criminal organizations—similar to individuals—would also want to reduce the probability of being apprehended while maximizing profits from their criminal enterprise—see Schelling (1967, 1971), Jennings (1984) and Dick (1995) for discussions on criminal organizations.[8]

Research that considers the spatial allocation of criminals has been conducted by Ratcliffe and Taniguchi (2011), Rasmussen et al. (1993), Mehay (1977), and Xue and Brown (2003).[9] However, these accounts highlight aspects of the criminal market, such as the spillover effects of increased law enforcement on neighboring jurisdictions or spatial choice models, to explain the location of crimes whereas the present work evaluates the use of space as a means of differentiation, protection, and power for competing criminals. Most closely related to this paper is work by O'Flaherty and Sethi (2010). By making use of

[1] Although this paper applies to criminal organizations more generally, obtaining information about the location and turf of an individual criminal or criminal organization is difficult, if not impossible to obtain. As such, the data on African-American gangs is used merely for expositional purposes.

[2] The purpose for the collection of this data was focused exclusively on African-American gangs. There has been a steady rise in gangs of other ethnicities (see Blankston (1998)) and this most certainly affects the geographic composition of African-American gang turf. The presentation of these figures is intended to display how significant the changes in the composition of the market have been in order to offer possible explanations for this variation.

[3] See California (1960, 1972, 1978, 1996) for information on the enforcement expenditures and population of cities that are presented in Table 2.

[4] For information about gang injunctions, see http://www.lapdonline.org/gang_injunctions and Grogger (2005).

[5] Examples of this work include Becker (1968), Polinsky and Shavell (1984), Ehrlich (1973), Stigler (1970), Levitt (1997), Imrohoroglu et al. (2004), Ashenfelter and Greenstone (2003), and DeAngelo and Hansen (2010).

[6] Glaeser et al. (1996) offers an excellent analysis of the role that social interactions play in the cross-city variability of crime rates. The current research complements the work of Glaeser et al. (1996) by offering a market based explanation of variability in crime rates due to the use of space as a product/price differentiation.

[7] Deutsch et al. (1987) use a similar set up to examine the conditions that would need to exist for a criminal to diversify his operating location.

[8] Schelling (1967) points out the interesting fact that victimless crimes, such as the sale of drugs, provide enough of a sustenance to warrant the organization of criminal activities: "It may be…that without these important black markets, crime would be substantially decentralized, lacking the kind of organization that makes it enterprising, safe, and able to corrupt public officials. In economic development terms, these black markets may provide the central core (or .infrastructure.) of the underworld business.'

[9] A technique known as crime or "hot spot" mapping is often used by criminologists. These methods use the locations of past criminal activities to predict future criminal locations.

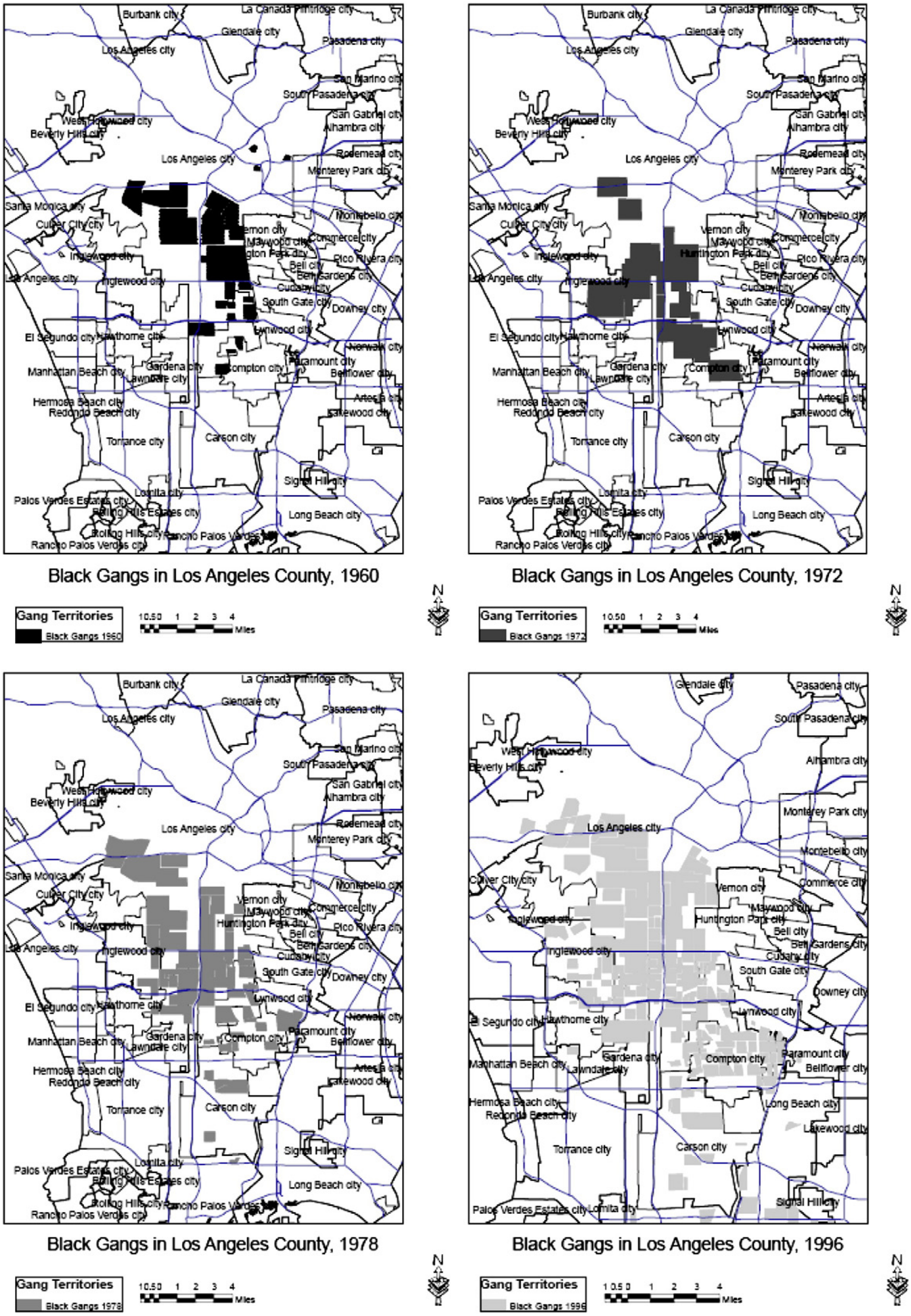

Fig. 1. African-American gang territories.

the circular city model—seen in Salop (1979)—the authors discuss the effect of vice crimes on the racial segregation and poverty levels in inner cities, finding that areas with higher demand for illegal goods will tend to have more tightly packed sellers in equilibrium. The current research, in contrast, relaxes the assumption of homogeneous suppliers and, instead, finds that sellers might not be tightly compact despite higher demand intensity. Moreover, the presence of law enforcement efforts is analyzed and displays the interesting result

Table 2
Enforcement expenditures per capita.

City	1960	1972	1978	1996
Carson	57.28	58.99	92.43	135.70
Compton	124.52	143.77	149.04	198.87
Gardena	56.34	126.21	162.43	214.16
Inglewood	74.06	188.30	308.62	380.07
Lakewood	23.09	79.96	63.34	93.27
Los Angeles	100.57	207.94	209.97	393.66

All figures are normalized to 2000 dollars.

that increased law enforcement efforts can actually increase the market share of criminals. I now proceed to discuss the details of the theoretical model.

3. Theoretical framework

In analyzing an alternative approach to understanding models of crime, I lean on research in the area of industrial organization that recognizes the impact of firm location decisions on market outcomes (e.g. market quantity and price). Hotelling (1929) and Salop (1979) provide critical analyses on the importance of locational choices for firms. One key difference in this paper is that the price charged for illegal goods in a market of heterogeneous criminals is endogenous.[10] I build on the spatial competition model of Vogel (2008) by considering an illegal goods market composed of individuals demanding the illegal good, criminals that deliver the good to the market and law enforcement that attempts to rid the market of the contraband. A criminal chooses an operating location and a price to charge in providing illegal goods to clients, but risks being apprehended by police.[11] Police populate the market with the task of preventing the exchange of proscribed goods. A spatial price competition model is adopted from Vogel (2008) in which a measure of the distance between competing criminals, the price charged for goods, market share, and profits of criminals as well as the fraction of people consuming illegal goods are endogenously determined. The interplay between enforcement efforts and criminals is then analyzed. A detailed description of the agents, information, and results of this model follow.

3.1. Clients

Clients populate the city and are endowed with an income and preferences over legal consumption, c_L, and illegal consumption, k. A potential client's utility is represented by the following separable utility function.

$$u(c_L, k) = u_0(c_L) + I \cdot k(n, g) \tag{1}$$

where $I = 1$ if the client obtains one unit of illegal good.

For simplicity, the utility obtained from consuming legal goods, $u_0(c_L)$, is assumed to be a standard utility function with $u'_0(c_L) > 0$ and $u''_0(c_L) < 0$ satisfying *Inada* conditions. If the client successfully consumes the illegal good, their utility is augmented by $k(n,g)$, properties of which are discussed later. The demand for illegal goods is inelastic and, for purposes of tractability, I assume that each client desires one unit of the illegal good.[12] The consumption of illegal goods can be restricted by the enforcement agents if the client is apprehended for soliciting an illegal activity.[13] In the spirit of Salop (1979) and Vogel (2008), I assume that the market region is the circumference of a circle with unit length. There is a mass of $N > 0$ clients and corresponding locations that are uniformly distributed along the circle being indexed by $n \in [0, 1)$. A client located at point n who receives goods from criminal g derives the following utility from receiving one unit of the illegal good

$$k(n, g) = v - p_g(\lambda_n) - tD(n, g) \tag{2}$$

where v is the common valuation of illegal goods, p_g is the price that criminal g charges, $D(n,g)$ is the shortest arc length separating client n from criminal g, and $t > 0$ is the per unit travel cost for the client. Client n incurs a utility cost of $tD(n,g)$ when obtaining an illegal service from criminal g, which is denoted the "shopping cost" for client n. The shopping cost has two interpretations. If the good is homogeneous across all criminals and is differentiated by the geographic location that the good is being offered, then one can think of the shopping cost as the cost the client incurs in traveling to criminal g. If it is a heterogeneous good (such as different quality cocaine or marijuana), then the shopping cost represents the utility a client loses by purchasing a service that differs from their ideal variety. Lastly, the price, $p_g(\lambda_n)$, charged by criminal g depends on the probability—denoted λ_n—that an exchange of illegal goods is intercepted by law enforcement at location n, where $p'_g(\lambda_n) > 0$.

The criminal that the client decides to frequent will depend on the *location-adjusted* price, $p_g(\lambda_n) + tD(n,g)$. Client n will, in a market of finite criminals G, purchase one unit of the good from $g \in G$ only if

$$g \in arg \min_{j \in G} \left\{ p_j(\lambda_n) + tD(n, j) \right\} \tag{3}$$

$$and \;\; p_g(\lambda_n) + tD(n, g) \leq v \tag{4}$$

Finally, a client who is indifferent between two criminals will frequent the criminal that is geographically closest. Additionally, I assume that v is large enough that every consumer in the market purchases one unit in equilibrium.

3.2. Criminals

There are $G \geq 2$ criminals operating on the unit circle city. Criminals provide illegal goods to clients, but must compete against other criminals to capture a share of the market. Criminals have a marginal cost, $c_g(\lambda_n, w_G) \geq 0$, of providing illegal goods. It is assumed that not all criminals have identical marginal costs. This could, of course, be due to a variety of reasons (e.g. unique information pertaining to the local market, access to a unique production technology, ability to disguise contraband, connections to drug producing countries, ability to elude enforcement).[14] However, we will focus on two aspects of the cost of

[10] For simplicity, throughout the theoretical model I refer to criminal organizations simply as a criminal. However, the intent is for the criminal organization to have a tractable territory/share of the market.

[11] Goods should be thought of as a catch-all phrase for illegal goods and services.

[12] This assumption is consistent with markets for addictive substances (see Caulkins and Reuter (2006), O'Flaherty and Sethi (2010) and Becker and Murphy (1988)) and markets for illegal goods (see Becker et al. (2006)). Additionally, Rhodes et al. (2000) find, in a document prepared for the National Institute of Justice, that the price elasticity of demand for Marijuana, Cocaine, and Heroin is quite small. However, users of Methamphetamines appear to be very responsive to prices.

[13] The presence of enforcement might raise concern to an individual that makes its goal the maximization of the utility of the individuals in the market since successful interventions by the enforcement agent reduces utility levels. However, the sale and use of drugs not prescribed to an individual is strictly prohibited in the US and many other countries throughout the world. Thus, the enforcement agents in this model act in accordance with observed practices.

[14] The assumption of seller heterogeneity would seem to imply a certain level of inelasticity of the supply of labor to the drug selling business. As noted in Freeman (1996), a collage of evidence supports the notion that young men respond substantially to the economic returns to crime. However, others—such as Kuziemko and Levitt (2004)—note that the production and distribution of drugs—such as cocaine—requires that the criminal incur very serious risks associated with the production, smuggling, and distribution of the drugs. In this sense, it would not seem to be the case that perfect replacement of a criminal that is incarcerated or killed is realistic. As such, there would seem to be a certain level of inelasticity associated with being a criminal, as is implied by heterogeneous criminals in the illegal goods market depicted in this paper. It is the heterogeneity of criminals that drives the differences in market share/distance between criminals that reinforces the level of inelasticity of criminals.

providing illegal goods to the market: law enforcement and protection of a criminal's turf. A criminal's marginal cost is impacted by the apprehension probability, λ_n, and the cost of fighting, w_G, such that $\frac{\partial c_g}{\partial \lambda_n}(\cdot)>0$ and $\frac{\partial c_g}{\partial w_G}(\cdot)>0$.[15] The impact of the cost of fighting on the criminal market will be discussed later. For simplicity, I assume that criminals choose an operating location and that all clients desiring the illegal good travel to the criminal. Therefore, criminal g's expected cost of providing the good to client n is

$$c_g(\lambda_n, w_G). \tag{5}$$

Lastly, criminals are assumed to have knowledge of the probability of getting apprehended. This knowledge is a probability distribution over all possible locations.

3.3. Enforcement

Enforcement, in this context, differs from the traditional concept of police clearances. Police are provided a technology that allows them to survey any location along the circle. However, the technology is costly to utilize.[16] The probability of a criminal activity being detected in location n depends on the probability that the technology is in use, which I denote λ_n. Initially, enforcement efforts are assumed to be allocated uniformly along the perimeter of the circle. In other words, the probability of being caught is equivalent across locations, such that $\lambda_n = \alpha$, where α is implicitly determined by allocating the police budget equally across locations. Moreover, α is known to the criminals and clients, as well as the enforcement agents. Criminals are not apprehended if the technology detects the exchange of illegal goods. Rather, the exchange of the illegal good is stopped. Although this is a slightly awkward concept of enforcement, it overcomes issues of criminals and clients falling out of the illegal market.

3.4. The game

The following discussion provides the framework of the illegal goods market in which the clients, criminals and law enforcement agents operate. First, the information available to the players in the game is discussed. Next, the process by which individuals enter the illegal goods market is discussed. Lastly, the timing of the game played by criminals is discussed and the equilibrium market outcomes are reached.

3.4.1. Information

The players that comprise the illegal goods market are armed with information that allows them to make decisions about purchasing, selling, and prohibiting the sale of goods. Criminals have information about the number of criminals currently in the market and utilize this information in deciding whether or not to enter the market. For the criminals that have entered the market, they are aware of the location of their competitors, the location of all clients, and the distribution of enforcement efforts. Clients are aware of the location of potential sellers of illegal goods, the prices that they charge, and the location of enforcement efforts in the market. This allows the clients to determine and frequent the lowest cost criminal. Lastly, law enforcement efforts are fixed in each location. The efforts that law enforcement can exert are uniformly distributed throughout the market, but can be reallocated over time.

3.4.2. Selection

Criminals are presumed to have a legal alternative to selling illegal goods. As such, individuals must determine whether they want to pursue legal or illegal activities. It is assumed that an individual would be interested in becoming a criminal if they could competitively provide illegal goods to the market. In the long run, only the most competitive criminals will remain in the market. Thus, it is further assumed that criminals can be ordered such that the most competitive criminals are currently in the market. Assuming that there are individuals not currently in the illegal market, some individuals could be induced into the illegal goods market. Should the price of participating in the illegal goods market increase (perhaps due to increased enforcement efforts), current criminals could be induced to leave the illegal goods market as well. The first individual that would be induced to leave (join) the illegal goods market is the individual who has the highest (lowest) marginal cost of producing illegal goods who is (not) currently a criminal. In this way, criminals that are on the margin of joining/dropping out of the illegal goods market have three decisions: whether to be a criminal or not, where to locate and what price to charge. However, the criminal that is considering joining/departing from the illegal goods market is aware of the number of criminals in the market and the distribution of marginal costs across criminals.

3.4.3. Timing

The timing of the decisions that are made by individuals in the illegal market plays a fundamental role in understanding the analytic solutions to the market equilibrium. Clients and law enforcement do not have sequential moves in this game. Instead, these players have fixed locations within the market. Criminals, on the other hand, play a three-stage game to determine their distribution location and selling price for illegal goods. In the *pre-entry* stage the criminal decides whether they will enter the illegal goods market or not. For those that decide to pursue an illegal means of income, a two-stage game of complete information is played. In the first stage, denoted the *location* stage, criminals decide where to locate, z, along the perimeter of the unit circle. In the second stage, denoted the *pricing* stage, criminals—observing the locations of all other criminals—simultaneously determine a price, $p_g(\alpha)$, to charge in providing goods to location n. Note that, in this model, the criminals assume that the individuals and enforcement agents are fixed in their locations.

3.5. Equilibrium outcomes

Given price $p_g(\alpha)$ and location z, there exists a set of clients, $\phi(z,p_g(\alpha))$, who will desire the good from criminal g.[17] Criminal g's profit from providing the good to this set of clients is

$$\pi_g = \int_{n\in\phi(z,p_g)}\Big(p_g(\alpha) - c_g(\lambda_n, w_G)\Big)dn. \tag{6}$$

The solution concept employed is that of a pure strategy subgame perfect Nash equilibrium (*SPNE*) in which no criminal randomizes over locations along the equilibrium path. A distillation of the equilibrium refinement is provided in Appendix A.

[15] The marginal cost of delivering goods to the illegal goods market is modeled as a function of the law enforcement efforts devoted to fighting crime and the resources required to protect one's turf. Law enforcement efforts drive up the cost of delivering illegal goods to the market, as increases in the amount of illegal goods delivered to the market require additional interactions both within the criminal organization and with clients and a higher number of exchanges of goods that could be apprehended (see Becker et al. (2006) and Baccara and Bar-Isaac (2008)). Levitt and Venkatesh (2000) note that gang wars are costly in terms of lives and profits lost. In fact, during times of gang warfare, the gang will sustain losses by pricing below the marginal cost in order to attract buyers that might otherwise be afraid to engage with the criminal organization. We model this loss in productivity through increases in the marginal cost due to fighting.

[16] Imagine a city where every location has a surveillance camera that, once turned on, can detect the exchange of illegal goods. However, turning the camera on and leaving it surveying is costly.

[17] See Vogel (2008) for a detailed description of how the set of clients, $\phi(\cdot)$, is computed.

Criminals along the perimeter of the circle are labeled in a clockwise manner from criminal g, such that the criminal to the immediate right is $g+1$. Given the prices that each criminal chooses, I assume that an indifferent client exists between each pair of criminals g and $g+1$. The price charged by an arbitrary criminal, p_g, and the distance, $d_{g,g+1}$, between two arbitrary criminals, g and $g+1$, can then be computed

$$d_{g,g+1} = \frac{1}{G} + \frac{2}{3t}\left(\bar{c} - \frac{c_g(\alpha, w_G) + c_{g+1}(\alpha, w_G)}{2}\right) \tag{7}$$

and

$$p_g = t\left(\frac{1}{G} + \frac{2}{3t}\bar{c}\right) + \frac{c_g(\alpha, w_G)}{3} \tag{8}$$

where $\bar{c}$ denotes the average marginal cost of providing the good in the market. Note that in the trivial case of a two criminal analysis ($G=2$), the second term of Eq. (7) becomes zero and the criminals will optimally locate on opposite sides of the city—the maximum distance between two criminals. Three propositions pertaining to the marginal impact of productivity and law enforcement on the distribution of criminals (distance between and market share), as well as the number of criminals in the market and profitability of each criminal are now discussed.

Proposition 1. *For $G>2$ the distance between adjacent criminals is decreasing in the average marginal cost of adjacent criminals.*

Proof. See Eq. (7).

Proposition 1 is driven by differences in the productivity of criminals. If neighboring criminals are relatively less productive than the average productivity of the illegal market, then the distance between neighboring criminals is driven toward zero out of survival. Less productive criminals must differentiate themselves from more productive criminals in order to obtain profits. Differentiation is accomplished through space. As a result, more productive criminals will find that they are isolated because less productive criminals will feel the need to become competitive to a segment of the market that is located further from their more competitive counterpart. In locating further from the more efficient competitor, the less productive criminal reduces the travel costs for this isolated market by reducing the price associated with purchasing the illegal good from the closer criminal rather than the lower cost, but spatially distant competitor.

Given the distance between and price charged by criminals, the market share, x_g, and profits, π_g, for criminal g can be computed. The market share for criminal g is the region between the criminal and the indifferent client in each direction. The profit that criminal g obtains is the sum of the *location-adjusted* price less the marginal cost of production over the entire market share. The market share and profits are displayed below:

$$x_g = \frac{1}{G} + \frac{2}{3t}\left(\bar{c} - c_g(\alpha, w_G)\right) \tag{9}$$

and

$$\pi_g = Ntx_g^2. \tag{10}$$

It is clear from Eqs. (9) and (10) that two items can affect a criminal's profitability: the number of potential clients N (also denoted the demand intensity) and the criminal's market share. Therefore, the implications of criminal heterogeneity on the market share of criminals also have implications for the profits that a criminal obtains, which are discussed in Proposition 2.[18]

Proposition 2. *For $G \gg 2$ the market share and distance between criminals is decreasing in their marginal cost.*

Proof. See Eqs. (7) and (9).

Proposition 2 explains the finding that the distance between criminals and the market share of a criminal will be reduced as a result of increased marginal costs of producing illegal goods. Thus, at the margin, an increase in a criminal's marginal cost—holding other criminal's marginal costs constant—is synonymous with decreasing that criminal's relative productivity. A criminal with decreased productivity will want to spatially differentiate themselves from relatively more productive criminals. This drives relatively less productive criminals toward one another and thus reduces the distance between and market share of that criminal.

In a similar vein, the effect of increases in enforcement on the structure of the illegal market can be studied. For example, if we allow enforcement to target specific areas—holding the enforcement efforts in other regions constant—this will drive up the marginal cost of producing and delivering the illegal good.

Proposition 3. *For $G \gg 2$ the market share and distance between criminals is decreasing in enforcement efforts in that region.*

Proof. See Appendix A.

Proposition 3 highlights the finding that increases in enforcement efforts drive up the marginal cost of production, thereby reducing the productivity of a criminal operating in that region relative to criminals in unaffected regions. Thus, criminals operating in the region that experiences increased enforcement efforts will find themselves relatively less productive and, as noted in *Proposition 2*, the market share and distance between the criminals will be decreased.

The number of clients that exists in the illegal goods market should also be noted. In order to profitably exist in the illegal goods market, the client must have a positive market share ($x_g>0$) as seen in Eq. (10). Given that clients are heterogeneous and can be ordered $1,2,3\ldots g$ (as discussed in the selection section), it could be the case that only a subset of all potential criminals will find it lucrative to enter the illegal goods market. We define the subset of criminals that do enter the market below:

$$G^* = \left\{ g \in G \,|\, c_g(\alpha, w_G) - \bar{c} < \frac{3t}{2G^*} \right\}. \tag{11}$$

Using Eq. (11) and given that we can order criminals, we let $c_g^i(\alpha, w_G)$ be the criminal that is indifferent between pursuing a life of crime and a legal means of income because they cannot obtain a positive market share. Thus, in equilibrium, the number of criminals will equal $\frac{3t}{2\left(c_g^i(\alpha, w_G) - \bar{c}\right)}$. This allows us to conclude two features about the number of criminals that will exist in the market in equilibrium. First, the number of criminals is increasing in the cost of traveling to obtain illegal goods. This is because higher travel costs will afford higher cost criminals the opportunity to enter the market, as clients will substitute lower cost illegal goods for higher cost, but geographically closer goods. Second, as higher cost criminals enter the market, the left side of Eq. (11) increases, as lower productivity criminals enter the market. This is because the average productivity in the market decreases simultaneously due to the entry of lower productivity

[18] Given the assumption that no entry is permitted once the game has begun, the profits and market share are both greater than zero since the only criminals that will exist in the market are the criminals that will find it profitable to do so.

criminals. However, the increase in the average marginal cost of production will be smaller than the increase in the marginal cost of the entering criminal.[19] The right side of Eq. (11) decreases due to the increase in G^*. Since the left side of Eq. (11) is increasing and the right side is decreasing, it is clear that an internal solution to the equilibrium number of criminals exists.[20] We now proceed to discuss the illegal goods market while allowing criminals to enter and exit the market.

3.6. Entry and the illegal goods market

Entry into the illegal goods market is quite prevalent.[21] In order to understand the impact of additional criminals on the structure of the market, I explicitly examine entry in a general equilibrium framework. To do so, I expand on the marginal cost term discussed above. The marginal cost of producing illegal goods will now be a function of two parameters: enforcement efforts, α, and the cost of fighting, w_G. As noted before, the marginal cost of production is increasing in enforcement efforts. As an additional assumption, the marginal cost of production is also increasing in the cost of fighting.[22]

To examine entry in the model, I will examine the effect of increases in the marginal cost on both entry to the market as well as the distance between criminals and their market share. In order to carry out this analysis, I first examine the effect of increases in the marginal cost on the distance between criminals and their market share. I then utilize Eqs. (7) and (9) to analyze how the market share and distance between gangs change with entry/exit, law enforcement efforts, and marginal costs. I now proceed to examine the effects of free and costly entry on the structure of the illegal goods market.

3.6.1. Free entry

The illegal goods market does not provide a legal means of protecting a criminal's turf, which I have denoted *market share*. As noted in Rasmussen et al. (1993), new entrants into an illicit drug market take predatory actions, cutting price or quality to gain a larger share of the market. Therefore, entering criminals provide a legitimate source of concern for pre-existing criminals throughout the city, as new criminals could enter the illegal goods market and dissipate their market share. I assume, for a brief time, that entry is costless and criminals do not fight among one another such that $w_G = 0$ and proceed to determine the general impact of new criminals on the entire structure of the illegal goods market.

Proposition 4. *For $G \gg 2$ with free entry and no fighting in the criminal market, an increase in the marginal cost of illegal goods production for low productivity criminals that results in at least one criminal exiting the market will increase the distance between and market share of criminals that remain in the market.*

Proof. See Appendix A.

Proposition 4 looks at the effect of an increase in the marginal cost of producing illegal goods for criminals with high marginal costs on the distance between and market share of criminals that remain in the market. This proposition finds a counteracting effect that is absent in *Proposition 2*. Namely, when entry and exit is permitted in the illegal goods market, an increase in the marginal cost of production for lower productivity/clustered criminals will push low productivity criminals closer together because they must spatially differentiate from higher productivity criminals. This leads to a reduction in the market share of low productivity criminals. Ultimately, the increase in the marginal cost of production could force high marginal cost criminals to drop out of the illegal goods market. More precisely, if the increase in marginal costs drives the left side of Eq. (11) high enough that the inequality no longer holds, then the least productive criminal no longer obtains positive profits from a life of crime and will exit the market. When this criminal exits the market, the left side of Eq. (11) falls while the right side increases, as discussed in footnote 19, in order to bring the market back into equilibrium. The reduction in criminals will yield more space for the remaining criminals and, hence, pull criminals apart, thereby increasing market share.

3.6.2. Costly entry and fighting

The previous section is now expanded to allow for costly entry and fighting among criminals. As noted in Rasmussen et al. (1993), the only viable alternative to predatory competition may be physical elimination of the competition through threats, intimidation, and violence. The use of violence in markets with rights that are not legally enforceable has received a fair bit of attention (See Reuter (1983), Canada (1995), and Donohue and Levitt (1998)). In what follows, the cost of entering and operating in the market will depend on the level of competition in the market, which is a function of the level of market saturation.[23] The entry and fighting costs are directly reflected in the marginal cost function, with $w_G > 0$. I now proceed to determine the impact of increased marginal costs on the structure of the illegal market when entry and fighting is costly.

Proposition 5. *For $G \gg 2$ with costly entry and fighting in the criminal market, an increase in the marginal cost of illegal goods production for low productivity criminals that results in at least one criminal exiting the market will increase the distance between criminals and the market share of criminals that remain in the market.*

Proof. See Appendix A.

Similar to costless entry, the increase in marginal costs for lower productivity criminals will push lower productivity criminals closer together to the point that at least one criminal can no longer profitably remain in the market. Given that entry and fighting is costly, the reduction in criminals leaves those criminals that profitably remain in the market more productive because they allocate less effort toward fighting. As a result of less competition, the criminals that remain in the market benefit from less competition in two ways. First, less competition leaves more space for criminals to operate. Second, fewer criminals requires that less resources are devoted to fighting other criminals in order to maintain market share. The effect of increased marginal costs of low productivity criminals has a similar impact on the market share of a criminal.

[19] The increase in marginal cost due to the entry of an additional criminal when there are currently g criminals in the market is $c_{g+1} - c_g$, whereas the increase in the average marginal cost is $\frac{c_{g+1} - \overline{c}_g}{g+1}$. Given that we have ordered criminals from most to least productive, it is clear that $c_g > \overline{c}_g$, thus the increase in marginal cost overwhelms the increase in average marginal cost.

[20] For example, suppose that there are *ten* potential criminals who have marginal costs that are uniformly distributed on (1,10). Suppose also that the transportation costs are $10 per unit distance. The equilibrium number of criminals in this market will be *five* criminals. At six criminals, the average marginal cost is $3.50 and rearranging equation 11 we conclude that $G^* < \frac{3t}{2(c_g(\alpha, w_G) - \overline{c})} = 6$. Thus, only five criminals can profitably exist in the market.

[21] California's Legislative Analyst's Office notes that there were over 250,000 new felony and non-felony arrests of juveniles in 2007 (most of which are drug offenses).

[22] In California, Governor Schwarzenegger introduced the California Gang Reduction, Intervention and Prevention Program (CalGRIP) initiative in May of 2007 to confront the dramatic increase in gangs across the state and their proliferation in suburban and rural areas. Governor Schwarzenegger also noted that although the level of crime in California has decreased over time, the number of gang related crimes has remained steady or even increased.

[23] Note that the cost of entry could have been included as a fixed cost. For example—and as noted in Vogel (2008)—the criminal could pay a fixed cost and then draw a marginal cost from a distribution in order to determine their level of productivity. The criminal could then determine if they would like to enter the market or not. Adding this component to the analysis would not significantly effect the two-stage game, except that it would reduce the number of criminals. However, this effect is captured by simply including costly entry as a component of the marginal cost function.

When entry into the criminal market is costly, an increase in the marginal cost of production could be a benefit to criminals from a general equilibrium perspective. Although some criminals will be forced to drop out of the market because they are no longer capable of competing against higher productivity criminals, the criminals that remain incur two benefits. First, there are fewer criminals in the market, yet the same number of clients demanding the illegal good. Second, a reduction in competition results in less resources being spent on fighting against other criminals to secure market share. If the effect of fewer criminals and less fighting between the criminals outweighs the loss in productivity, we should expect a criminal's market share to be increased.

Finally, the structure of the market—with costly entry—can be impacted by changes in enforcement efforts. *Proposition 6* examines the effect of increased enforcement efforts on the structure of the market.

Proposition 6. *For $G \gg 2$ with costly entry into the criminal market, an increase in enforcement efforts that targets and eliminates low productivity/geographically clustered criminals will increase the distance between and market share of criminals not forced out of the market.*

Proof. See appendix A.

Proposition 6 highlights a striking finding on the interplay between criminals and law enforcement. Namely, when law enforcement efforts target low productivity criminals, the criminals that are not scrutinized can increase (a) the distance between themselves and their neighboring criminals and (b) their market share. A criminal can experience an increase in the distance between themselves and neighboring criminals and an increase in market share if the reduction in low productivity criminals and corresponding reduction in fighting outweigh the reduction in productivity that occurs from increasing enforcement efforts in a particular region. Counterintuitively, though, this effect highlights a potential source of frustration for law enforcement officials. By focusing enforcement efforts on regions that have higher densities of criminals and criminal fighting, they will force lower productivity criminals out of the criminal market. While this seems like a desirable outcome, it actually has one significant drawback; higher productivity criminals will absorb the clients that the lower productivity criminals used to serve, which will increase their profits. On the other hand, if law enforcement targets higher productivity/spatially differentiated criminals that are providing the good to a larger number of clients, this will make entry to the criminal market more attractive.[24] As a result, targeting higher productivity criminals can induce entry into the criminal market.

4. Conclusion

This paper extends the literature on the markets for crime by developing a framework from Hotelling (1929), Salop (1979), and Vogel (2008) where criminals endogenously differentiate themselves spatially. An imperfectly competitive, spatial model of crime is presented in which criminals provide heterogeneous goods to potential clients. Surprisingly, the price, market share, and profits of a criminal are affected by his competitor's marginal cost only through the competitor's effect on the average marginal cost of the market. The distance between adjacent criminals is computed and is not only impacted by the average marginal cost of the market, but also the relationship between the average marginal cost of adjacent criminals relative to the average marginal cost of the market.

The model is then extended to account for the impact of law enforcement efforts. Three main predictions are reached. First, when entry and fighting among criminals are omitted from the analysis I find that criminals who experience a decrease in productivity will differentiate themselves by spatially separating from relatively more productive criminals. Second, when entry and fighting are taken into consideration, criminals who face a decrease in productivity do not spatially differentiate if the decrease in criminals and efforts devoted to fighting offset their reduction in productivity. Third, increases in law enforcement efforts can increase the market share of a criminal if the increased law enforcement efforts drive competing criminals out of the market.

The interplay between law enforcement and organized criminal organizations has been analyzed by Garoupa (2007), Clentani et al. (1995), and Kugler et al. (2005). This paper goes beyond previous work, however, by providing a framework in which criminals have a degree of control over the price of illegal goods, criminals can spatially differentiate themselves, and productive efficiency is taken into consideration when determining the effectiveness of law enforcement efforts.

The theoretical model of organized criminal organizations and law enforcement adopted in this paper can be expanded in several ways. To start, allowing enforcement to reallocate in a less structured manner could yield significant insights. For instance, it would be fruitful to allow the allocation choices for law enforcement efforts to be endogenized to take criminal location and criminal activities into consideration. Also, an empirical examination of the illegal goods market that uses individual level information about illegal goods transactions and gang warfare could prove to be a very powerful predictive instrument, particularly in the war on drugs and crime.

Appendix A

Explanation of equilibrium refinement

Suppose that three criminals, denoted A, B, and C, are located along a line. It has been shown by d'Aspremont et al. (1979) that no pure strategy SPNE exists as the profit functions of the criminals are neither continuous nor quasi-concave in the price-stage subgame. This is due to the ability of a criminal, say criminal A, to undercut, by an arbitrarily small amount, the price charged by another criminal, say criminal B, and gain a discrete mass of clients. Thus, there exist prices at which criminal A's market share and, therefore, profits are discontinuous. To overcome this problem, demand systems are altered so that price reductions by criminal A do not gain a discrete mass of clients. According to the refinement presented in Vogel (2008), a reduction in price charged by criminal A yields a corresponding increase in the number of clients that gang A serves by finding the new, indifferent consumer between A and B. For a thorough explanation of the uniqueness and existence of the equilibrium with refinement conditions used in this document, see Vogel (2008).

Proposition 3

Proof. Suppose that enforcement costs are increased in one area, holding the enforcement level constant in all other regions. Differentiating Eqs. (7) and (9) with respect to enforcement efforts yields the impact of enforcement efforts on the market share and distance between adjacent criminals in that location.

$$\frac{\partial d_{g,g+1}}{\partial \alpha_g} = -\frac{1}{3t}\frac{\partial c_g}{\partial \alpha_g} \tag{12}$$

$$\frac{\partial x_g}{\partial \alpha_g} = -\frac{2}{3t}\frac{\partial c_g}{\partial \alpha_g} \tag{13}$$

Since $\frac{\partial c_g}{\partial \alpha_g} > 0$, it is clear that the effect of increases in enforcement efforts decrease both the distance between adjacent criminals and the market share of criminals in location g. □

[24] The increased relative productivity results from $\overline{c}$ increasing due to enforcement efforts that target higher productivity criminals. This effectively reduces the right side of Eq. (11) and entices individuals not currently in the market into entering.

Proposition 4

Proof. Suppose that the marginal cost of producing illegal goods increases for a low productivity criminal, $g+1$, that is a neighbor to criminal g and that entry into the market is free. Totally differentiating Eqs. (7) and (9) with respect to marginal costs yields the impact of the increase in marginal costs to criminal $g+1$ on the distance between criminal g and $g+1$ and the market share of criminal g.

$$\frac{\partial d_{g,g+1}}{\partial c_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial c_{g+1}} - \frac{1}{3t} \tag{14}$$

$$\frac{\partial x_g}{\partial c_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial c_{g+1}} - \frac{2}{3t} \tag{15}$$

As seen by comparing Eqs. (14) and (15) to the derivative of Eqs. (7) and (9), respectively, when entry is not permitted an extra term exists. Namely, the first term in Eqs. (14) and (15) accounts for entry into the area that criminal g serves. Since $\frac{\partial G}{\partial c_{g+1}} = -1$, the first term of Eqs. (14) and (15)—coined the *reduction in criminals* effect—is positive. In other words, as the marginal cost to criminal $g+1$ increases, criminal $g+1$ exits the market. The second term in Eqs. (14) and (15) denotes the reduction in productivity that criminal g experiences due to criminal $g+1$'s departure. When criminal $g+1$'s productivity is reduced to the point that he must drop out of the market, this decreases the average marginal cost in the market and effectively makes criminal g less productive. As a result, criminal g's market share is reduced. The *reduction in criminals* effect must be weighed against the *reduction in productivity* effect. Whichever effect dominates will determine the change in the size of the market share and distance between criminals. □

Proposition 5

Proof. Suppose that the marginal cost of producing illegal goods increases for a low productivity criminal, $g+1$, that is a neighbor to criminal g and that entry into the market is permitted, but costly. Totally differentiating Eq. (7) and (9) with respect to marginal costs yields the impact of the increase in marginal costs to criminal $g+1$ on the distance between criminals g and $g+1$ and the market share of criminal g.

$$\frac{\partial d_{g,g+1}}{\partial c_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial c_{g+1}} - \left[\frac{1}{3t}\frac{\partial c_g}{\partial w_g}\frac{\partial w_g}{\partial G}\frac{\partial G}{\partial c_{g+1}}\right] - \frac{1}{3t} \tag{16}$$

$$\frac{\partial x_g}{\partial c_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial c_{g+1}} - \left[\frac{2}{3t}\frac{\partial c_g}{\partial w_g}\frac{\partial w_g}{\partial G}\frac{\partial G}{\partial c_{g+1}}\right] - \frac{2}{3t} \tag{17}$$

As seen by comparing Eqs. (16) and (17) to the derivative of Eqs. (7) and (9), respectively, when entry is not permitted, two extra terms exist. The first term in Eqs. (16) and (17) accounts for entry into the area that criminal g serves. Since $\frac{\partial G}{\partial c_g} = -1$, the first term of Eqs. (16) and (17)—coined the *reduction in criminals* effect—is positive. In other words, as the marginal costs to criminal $g+1$ increase, criminal $g+1$ exits the market. The second term in Eqs. (16) and (17) accounts for the reduction in fighting between criminals for a client base. Since we assume $\frac{\partial G}{\partial c_g} > 0$ and $\frac{\partial w_G}{\partial G} > 0$, the second term of Eqs. (16) and (17)—coined the *reduction in criminal fighting* effect—is also positive. This means that an increase in the marginal cost of producing illegal goods for criminal $g+1$ that results in criminal $g+1$ exiting the market will lead to less fighting. However, when criminal $g+1$ exits the market, this drives the average marginal cost of production downward. As a result, criminal g is effectively less productive when criminal $g+1$ exits the market. This is depicted in the third term of Eqs. (16) and (17), which is denoted the *productivity* effect. Therefore, the market share of a criminal increases if the *reduction in criminals* and *reduction in criminal fighting* effects outweigh the *productivity* effect. □

Proposition 6

Proof. Suppose that enforcement efforts are increased in areas where many criminals operate and results in criminal $g+1$ exiting the market. Recall that this clumping of criminals results from low productivity criminals needing to spatially differentiate from higher productivity criminals. Totally differentiating Eqs. (7) and (9) with respect to enforcement efforts yields the impact of the increase in enforcement effort on the distance between and market share for criminal g (a criminal that does not exit the market).

$$\frac{\partial d_{g,g+1}}{\partial \alpha_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial \alpha_{g+1}} - \left[\frac{1}{3t}\frac{\partial c_g}{\partial w_g}\frac{\partial w_g}{\partial G}\frac{\partial G}{\partial \alpha_{g+1}}\right] + \frac{1}{3t}\frac{\partial \bar{c}}{\partial G}\frac{\partial G}{\partial \alpha_{g+1}} \tag{18}$$

$$\frac{\partial x_g}{\partial \alpha_{g+1}} = -\frac{1}{G^2}\frac{\partial G}{\partial \alpha_{g+1}} - \left[\frac{2}{3t}\frac{\partial c_g}{\partial w_g}\frac{\partial w_g}{\partial G}\frac{\partial G}{\partial \alpha_{g+1}}\right] + \frac{2}{3t}\frac{\partial \bar{c}}{\partial G}\frac{\partial G}{\partial \alpha_{g+1}} \tag{19}$$

Eqs. (18) and (19) display the three effects at work when enforcement efforts are increased in the location where criminal $g+1$ operates. The first term displays the *reduction in criminals* effect. Since $\frac{\partial G}{\partial \alpha_{g+1}} = -1$, the first term is positive. The second term displays the *reduction in criminal fighting* effect. Since we assume $\frac{\partial G}{\partial c_g} > 0$ and $\frac{\partial w_G}{\partial G} > 0$, the second term of Eqs. (18) and (19) is positive. The final term displays the *reduction in productivity* effect. Since the increase in enforcement efforts reduces the number of low productivity criminals, this decreases the average marginal cost of criminals in the market. As a result, criminal g becomes relatively less productive and, hence, the third term is negative. The first two effects (*reduction in criminals* and *reduction in criminal fighting*) increase the distance between and market share of criminals. The final effect (*productivity*) reduces the distance between and market share of criminals that remain in the market. Thus, the distance between criminals and the market share of a criminal increases if the first two effects outweigh the third effect. □

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