NBER WORKING PAPER SERIES

IT'S THE PHONE, STUPID:
MOBILES AND MURDER

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Working Paper 25883
http://www.nber.org/papers/w25883

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 2019

We would like to thank Jerome Fox, Jonathan Heathcote, Thomas J. Holmes, Don Johnson, Ewan Kwerel, Eva Meyersson, Dan O'Flaherty, Emily Owens, Christopher Ruhm, Michael Riordan, Rajiv Sethi, Rodrigo Soares, Patrick Sun, and seminar participants at the Minneapolis Federal Reserve, Bristol University for helpful comments. Christiane Szerman and Laisa Rachter provided excellent research assistance. All errors are ours. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 25883
May 2019
JEL No. I0,I18,R0

ABSTRACT

US homicide rates fell sharply in the early 1990s, a decade that also saw the mainstreaming of cell phones – a concurrence that may be more than a coincidence, we propose. Cell phones may have undercut turf-based street dealing, thus undermining drug-dealing profits of street gangs, entities known to engage in violent crime. Studying county-level data for the years 1970-2009 we find that the expansion of cellular phone service (as proxied by antenna-structure density) lowered homicide rates in the 1990s. Furthermore, effects were concentrated in urban counties; among Black or Hispanic males; and more gang/drug-associated homicides.

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1 Introduction

In the 1990s, US homicide rates fell sharply and have stayed low since, remarkable considering that the past decades have seen booms and busts; growing income inequality; burgeoning substance abuse [Desimone, 2001, Case and Deaton, 2015, Ruhm, 2018], rising gun sales; and since 2008, declining incarceration rates [Kaeble and Cowhig, 2018].[1]

This paper investigates the role of cell phones for the decline in homicides. The 1990s is when cell phones[2] became mass market items thanks to drastic product improvements and lower prices.[3] The decade saw the number of subscribers go from five to 100 million.[4] Underpinning this development were technological advances and greater competitive pressure boosted by the 1993 Omnibus Budget Reconciliation Act, title VI. The Act authorized the FCC to make additional spectrum available through public auctions. We hypothesize that the mainstreaming of mobile voice and text services reduced homicides by reducing the role of street dealing in the retailing of illicit drugs.

Before cell phones, open street sales was a common way for end users to buy illicit drugs. At least part of the transaction had to be open because buyers and sellers needed to physically spot each other. Thus, a suitable venue combined accessibility and visibility with staying under the radar of law enforcement or "concerned citizens." As a result, street sales would typically be limited to a few marginal but open-to-the-public locations, e.g., poorly supervised street blocks, intersections, underpasses, or public-housing common areas.

The cell phone changed the reliance on such locations ("turf"). Cell phones allow buyer and seller to connect without being within each others field of vision. Furthermore, cell phones allow for real time coordination and provide a level of privacy. In the words of Murray [2001, page 51]: "[Cell phones] offered something completely new: Dialing a phone number now meant connecting with a *person* rather than a *place*."

The move away from turf-based dealing reduced violence principally through its effects on gangs, we propose. Simply put, as the turf lost its value, so did the turf war.[5]

Turf had value because its access could be controlled. Competing sellers could be spotted and kept off the turf, allowing the dominant entity (drug gang) to reap oversized economic gains. In addition to the violence generated in the gang's everyday dealings (settling scores, fighting off rivals, imposing internal discipline, etc.), high profitability may have created violence around the fringes as aspiring or low-ranking gang members sought to establish their *bona fides* by acting tough [Johnson et al., 2000, Levitt and Venkatesh, 2000]. A move away from turf-based dealing may have reduced the ability to cartelize drug sales, dented profits, and dulled the allure of gang life.

[1] Studies pointing to a positive relationship between guns and homicide include Duggan [2001], Koenig and Schindler [2018].

[2] Or more broadly, two-way Commercial Mobile Radio Services, a class that includes Specialized Mobile Radio (SMR) and Personal Communication Services (PCS). For brevity, when there is little risk of confusion, we will use the term cell phone to refer to this whole class.

[3] See for instance the Federal Communications Commission's Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services, various years.

[4] CTIA-The Wireless Association.S

[5] Collins online dictionary: A turf war is a struggle between criminals or gangs over who controls a particular area.

Additionally, cell-phone uptake may have reduced the incidence of altercations surrounding drug sales since phones allow for the transaction to be broken up – notably the payment and the delivery can be handled separately. Moreover, the venue can be where the dealer has a "home advantage," for instance indoors at a "dealer friendly" location, further reducing the risk of robbery.

Modern mobile wireless communication is made available by calls being handled through a network of hexagonal cells. The concept was worked out in the 1960s and the first prototype call was placed in 1973. Commercial service, however, had to wait another ten years. In 1983 the infrastructure was in place to offer the service commercially in Chicago and the Baltimore-DC area (having operated there on an experimental basis since 1977). Other major cities followed in 1984. Initially, coverage was limited to the subscribers "home" city; truly national coverage would be another 15 years. Furthermore, the handsets were expensive, mono-functional, and barely portable (often designed to work in cars, so called "car phones").[6]

The FCC had made spectrum available for this new cell phone service, but the lure of the new business opportunity turned the tried and true application procedure on its head as applications flooded the FCC. As a result, the FCC looked for a different allocation procedure and settled on allocation by lottery, the first of which was held in the spring of 1984. Each market was given two licenses, one which was given to the existing wireline operator and the other one to a non-wireline provider. The result was a sleepy duopoly of Baby Bells and local providers, a situation that would not be long lived [Murray, 2001].

The 1990s is replete with milestones, from the first SMS to the 100-million subscriber mark. However, the year 1993 stands out. First, the 1993 Omnibus Budget Reconciliation Act made additional spectrum available for Personal Communications Services (PCS), a wireless technology that was digital from the start and provides a service very similar to cellular telephony (the first auction opened in December 1994). Second, in 1993, AT&T entered the wireless phone business with the purchase of McCaw Cellular Communications (the merger was completed in 1994). Third, 1993 is when a third, hitherto overlooked, system went on-line in LA. Using dispatch spectrum bought on the cheap and equipment developed by Motorola, Nextel (formerly Fleet Call) offered a radio that also worked as a phone, and *vice versa*. All of this was underpinned by technological developments that increased spectrum carrying capacity, notably the transition from analogue to digital telephony.

This side of the 1990s, antenna construction has continued apace, but the expansion has been more about improved rural and national coverage and meeting the demands of data-intensive applications (the iPhone was introduced in 2007), than basic voice and text services (in urban areas) at the center of our hypothesis. Therefore, we do not expect antenna structure expansion after 2000 to have had the same homicide-lowering impact.

To obtain plausibly exogenous variation in cell-phone mainstreaming, we rely on network build out. Mobility in modern mobile telephony is achieved by a cellular network, where each cell consists of an antenna structure (e.g., a tower), antennas, and a base station. As the caller moves between cells, the call is handed from one cell to another. To a first approximation, more antenna structures mean more cells and more cells mean better service.

[6]Wikipedia: "The Motorola DynaTAC 8000x commercial portable cellular phone received approval from the FCC on September 21, 1983. It was priced at $3,995 in 1984, its commercial release year, equivalent to $9,209 in 2016 dollars."

The Federal Communications Commission (FCC) maintains a public register of all antenna structures taller than 200 feet above ground. The register contains information on location and year of construction, allowing us to construct a local (county-level) measure of antenna density by year.

Our identifying assumption is that the build out of the cellular network generated exogenous variation in consumer uptake of mobile telephony. We think this is a reasonable assumption for the 1990s when affordability and versatility of cell phones took major steps forward due to technological and regulatory advances. It was also a decade of rapid antenna structure build out, see Figure 1. This assumption loses validity with distance to the 1990s.

Studying annual, county-level vital statistics mortality data for the contiguous US covering the four decades 1970-2009, we find support for our hypothesis that expansion of cellular phone service – as proxied by antenna structure build out – lowered homicide rates in the 1990s, the decade the service gained mainstream use. Turf is an urban phenomenon and we find the effects to be concentrated in urban counties (counties part of a Consolidated Statistical Area (CSA)) and absent in non-urban ones. Turning to demographics, gang membership skews young (under 18), male, and Black or Hispanic,[7] and we find stronger effects for these groups.

To drill down on the hypothesis that cell phones reduced gang related homicides (as opposed to, for instance, just making it easier to call the cops which presumably would reduce all types of homicides) we use information on homicide circumstance and victim-offender relationship from by the Supplementary Homicide Reports (SHR) provided by the Federal Bureau of Investigation (FBI). Unlike vital statistics data, FBI data reporting is voluntary and the detail richness of the SHR is somewhat tempered by less than full coverage and a substantial fraction of cases being "undetermined." That said, using the SHR data we find antenna-structure build out to have had a stronger impact on homicides more closely linked to gang and drug activity (e.g., juvenile gang killing) than on homicides with less of a link (e.g., hunting accident). Turning to the victim-offender relationship, the overall picture again is supportive, with homicides by strangers being among the types of homicides most affected by antenna-structure build out. Furthermore, we find no effect for wife killings, consistent with gang members or drug dealers not being the marrying kind.

Our findings are robust to the inclusion of area-specific time trends (at the Consolidated Statistical Area (CSA) level) and do not appear confounded by illicit drug use (which according to our hypothesis would be facilitated by antenna structure build out) or economic activity as measured by county level overdose and employment rates respectively.

Many types of crime fell in the 1990s, not just homicide. We focus on homicide because it is a crime that is close to our hypothesis. It is also a well measured crime; the statistics are not susceptible to changes in victim propensity to report or arrest probability. While determination can be open to some slippage, once a death is considered a homicide, reporting is close to 100% [Bureau of Justice Statistics, 2014]. That said, homicide rates may correlate positively with other crimes and thus provide a window on them for two reasons. First, while homicide can be the intended end point, it can also be the deadly outcome of another crime [Maltz, 1999], say robbery or assault, in which case homicide

[7] For instance, National Gang Center. National Youth Gang Survey Analysis. Retrieved March 11, 2018, from `http://www.nationalgangcenter.gov/Survey-Analysis`.

may just be the tip of the crime iceberg. Second, we hypothesize that high homicide rates were driven by a weaponized gang environment, a factor that itself may give rise to crime.[8] A person carrying a gun for gang business may be tempted to also use it to steal or rape.

While almost a quarter century ago and time-bracketed, what brought down crime in the 1990s remains topical. First, our hypothesis suggests that the fact that homicide rates have stayed low reflects a fundamental regime shift. In other words, increases in homicides, while alarming in their own right, need not signal a return to the bad old days. Second, while the 1990s crime reduction need not be reproduceable (cell phones are not going anywhere), our findings suggest that the relationship between drug dealing and violence is complex and mediated by market conditions (broadly speaking). Third, our paper relates to a small but growing literature on the equally growing substance abuse crisis where two phalanxes have crystalized, one viewing substance abuse through the prism of economic decline [Case and Deaton, 2015] and one that has drawn attention to the proliferation of prescription drugs [Ruhm, 2018]. We add low prices and ready availability of illicit drugs to the mix.

The remainder of the paper is structured as follows: Section 2 provides a brief background on cellular telephony and the gang-drug-violence nexus. Section 3 describes the empirical strategy and Section 4 the data used. Section 5 presents results. Section 6 concludes. But first, we discuss the related crime literature.

1.1 Related Literature

We are by no means the first to study this topic, for reviews see e.g., Levitt [2004], Roeder et al. [2015], O'Flaherty and Sethi [2015].[9] One strand of explanations has focused on reduced criminality of the cohorts coming of criminal age in the 1990s, highlighting factors such as lead abatement [Reyes, 2007, Aizer and Currie, 2017] or abortion liberalization [Donohue and Levitt, 2001].[10]

Other studies have emphasized contemporaneous factors such as economic opportunities; urban renewal [Diamond, 2016]; crack cocaine [Grogger and Willis, 2000]; policing policies, incarceration rates, or other facets of the criminal justice system [Kuziemko and Levitt, 2004, Chalfin and McCrary, 2017]. However, the 1990s and the 2000s through 2006 were economic boom years, followed by the greatest bust since the 1930s, and all the while economic inequality kept rising. Still crime fell and has remained low. Perhaps unsurprisingly, the evidence on the role of the economic environment has been inconclusive [Gould et al., 2002, Bushway et al., 2012]. As for the role of urban renewal, a level of interrelatedness is bound to exist if only because a more upscale demographics is less crime prone themselves. It is worth noting, however, that the ascendancy of centrality (to the city center) as a prized amenity has long been in the making. In fact it was evident already in the 1980s [Edlund et al., 2016] but apparently did little to stop the crime wave of the late 1980s and early 1990s.

[8]For evidence on the drugs-guns-homicide link, see Evans et al. [2018].

[9]For popular press coverage, see for instance, Neil Howe "What's Behind The Decline In Crime?" *Forbes* 28 May 2015; Dara Lind and German Lopez "Why did crime plummet in the US? *Vox* 19 January 2016 `https://www.vox.com/cards/crime-rate-drop`; Matt Ford "What Caused the Great Crime Decline in the U.S.?" *The Atlantic* 15 April 2016.

[10]For a critique, see Foote and Goetz [2008]).

As the crack epidemic receded, so did the crime wave (Grogger and Willis [2000], also see Figure 2). However, explanations focusing on crack cocaine raise the question why drug use since has not resulted in similar or higher levels of violence. At least judging by overdose deaths, drug use has been steadily increasing since the 1980s, e.g., Jalal et al. [2018]. Certainly, overdose deaths have become more rural and more white, but that is a relative statement; in absolute terms, deaths have risen in urban areas as well.[11]

The second half of the 1990s saw a move away from open, visible-to-all street transactions to indoor dealing. The change has been described as partly motivated by an interest in protecting against robbery and partly as a response to more aggressive policing, and the role of mobile radio communication in this change has also been noted [Furst et al., 1999, Johnson et al., 2000].

Thus, the link between cell phones and modes of drug dealing is not novel to us. Nor is the link between drug dealing and violent crime. However, to the best of our knowledge, we are the first to splice the two. We are also the first, to the best of our knowledge, to investigate the cell-phone-homicide link empirically.

Our paper picks up a thread of the criminology literature that has noted the crime reducing capability of technological advances, although the emphasis has tended to be on the edge technology lends law enforcement or law-abiding citizens. Surveillance cameras, alarm systems, locks, etc. have all improved. Car locks are a case in point. Car theft used to be relatively low-skill, requiring little more than a blank key and a hammer. Starting in 1990, high end cars began to come equipped with mobilization technology. To start the engine, a computer chip embedded in the key fob was required, rendering old-fashioned bumping ineffective. However, uptake in the US was gradual and slow. By 2000, only about 10 percent of cars were fitted with transponders [van Ours and Vollaard, 2016, figure 2], undermining the case for this technology to have played a major role in the decline in violent crime.[12] Technological advances also underpinned the "broken-windows" policing policies popularized by the New York City Police Department.[13] Lastly, advances in computing power have reduced the amount of cash in circulation and thus the gains from robbery.[14]

Thematically, our paper may be most closely related to Bertoloai and Scorzafave [2018] who proposed that the use of cell phones among Brazilian inmates reduced homicides. Their hypothesized mechanism, however, is quite different from ours. Cell phones, they argued, allowed one gang to gain hegemony within the prison system by facilitating coordinated, in-prison attacks on rival gang members; this in-prison hegemony could then be leveraged to drug-dealing hegemony throughout the state since dealers caught were likely to end up in a gang controlled prison.

2 Background

This section motivates our hypothesis for why cell phones may have reduced violence in the US, and why in the 1990s. To that end we will briefly discuss drug dealing and the

[11] For the 1999-2015 period, see Mack KA [2017, table 2].

[12] For instance by restricting the availability of getaway cars. The share of homicides directly attributed to motor vehicle theft is exceedingly small, see Table A1.

[13] Specifically, the computer program CompStat `https://en.wikipedia.org/wiki/CompStat`

[14] As for drug-sales linked robberies, payment by cryptocurrency reduces the risk further. However, these currencies appear, by and large, outside of our study period. Bitcoin was launched in 2009.

use of violence in illegal organizations, but we start with a much abbreviated description of the development of mobile telephony.

2.1 Mobile telephony

Mobile radio communication was first used by the police force in the 1920s and the technology found extensively military use in World War II. The modern concept of low-power transmission in hexagonal cells was worked out in the 1960s. In 1973, Martin Cooper of Motorola placed the first cellular phone call from a makeshift base station in Midtown Manhattan to Bell Labs in New Jersey. However, mobility required the construction of a cellular network and it would take another 10 years for the service to be offered, and then only in Chicago and the Baltimore-DC area. Other major cities followed the next year, but coverage was typically city specific. Service outside the home city required jumping through hoops and incurred additional charges, if offered at all.

In the 1980s, the network was analogue and could only handle a handful of phone calls at a time. The phones themselves were expensive, bulky, and designed to be used in cars. In 1986, a "pocket phone" hit the market weighing in at 15 ounces and $3,295 [Murray, 2001, page 214]. Unsurprisingly, use was largely limited to businesses (including, presumably, drug smugglers and wholesalers).

Broad consumer uptake had to await the 1990s. Digital telephony (2G) was launched in 1991 and the first text message was sent the year after. The transition from analogue to digital considerably expanded network capacity. Simply put, a phone call between points A and B can be likened to highway traffic between them. Analogue technology is the equivalent of an entire lane being dedicated to a call, limiting call capacity to the number of lanes. Digital telephony, on the other hand, is more like regular use of a highway, each car occupying only a fraction of lane space.[15]

In 1993, the FCC was tasked by Congress with promoting competition in Commercial Mobile Radio Services (CMRS), a newly created category grouping services that allow for one or two-way mobile communication using radio waves. CMRS include pagers, Specialized Mobile Radio (SMR) services, Personal Communication Services (PCS), and cellular telephony. These services used different part of the spectrum, but in the second half of the 1990s, the services offered converged enough to make them (save pagers) highly interchangeable to the consumer. Furthermore, 1993 also heralds AT&T entry into the cellular market. Below description draws heavily on [Murray, 2001].

PCS: PCS Spectrum Auctions The 1993 Omnibus Act also allocated more radio spectrum to be used for PCS. Since PCSs were all-digital to start with, they expedited the digital transition. In addition, the cells for PCS were smaller (because of the higher frequency band), which allowed for lower power and thus longer battery life, all features that made PCSs a formidable competitor to cell phones.

In addition to more spectrum, Congress gave the FCC one year to switch to an auction based allocation mechanism, one that had many advantages over its two predecessors (winners appointed through comparative hearings or lottery). In December 1994 the current practise of spectrum-licence auctioning saw the light of day.

[15] To continue the car analogy, in a digital phone call, parts of speech is packed up and sent down the highway to be unpacked at the destination. A call would require not one but several cars. Still, one lane would be able to handle many simultaneous calls.

In 1995, the first commercial PCS went live under the brand name Sprint Spectrum.

SMR: Nextel In the late 1980s, a then FCC lawyer realized that under-used frequency bands close to the cell-phone bands could be used for mobile wireless communication.[16] Years of lobbying and a collaboration with Motorola later, Nextel went on-line in Los Angeles in 1993. After some initial glitches, including poor handsets, Nextel and its push-to-talk radio phones offered a product functionally approaching that of PCSs/cell phones but at lower cost.

Cellular: AT&T AT&T had left cellular telephony to its regional offspring (Regional Bell Operating Companies RBOCs) and had thus sat out the 1980s without any presence in the growing cellular business. Each area (say city) had been allocated two licenses, one of which was up for grabs, the other one was given to the wireline operator. While the non-RBOC operator constituted competition, they were fractionalized and often could not even offer regional coverage. As a result, a sleepy duopoly characterized the cellular market in the 1908s.

This cosy arrangement changed with AT&T's acquisition of McCaw Cellular Communications in 1993. Suddenly, the company that used to be synonymous with telephony was in the game, adding to the competitive pressure presaged by PCSs and SMR services.

The entry of AT&T brought nationwide coverage one step closer. The way in which spectrum had been allocated (by lottery for a decade) and a "free market" approach to the industry meant that the US market was highly fractionalized (compared to those in Western European countries), with phones, switches, even billing, being unable to handle calls across operators, and operators were often local. Seamless, cheap, nationwide calling was an obvious goal that could make wireless telephony become an everyday service. In 1998, AT&T introduced the first flat-rate plan with national coverage, the Digital One Rate plan. It was an instant success.

Meanwhile, handsets improved with beefed up programmability, functionality, and battery life all while shedding bulk and weight. For instance, in 1994, Motorola introduced the MicroTAC, which retailed for around $600 ($970 in 2016$), substantially lower than the $4,000 price tag of the initial phones (in 1983 or $9,000 in 2016$).[17] In 1995, the Nokia GSM phone, yet cheaper, lighter, and more versatile, became available on the American market.

Going into the 1990s, phone plans varied in a myriad of ways: the charge for incoming and/or outgoing calls; the first minutes of a call; the time of the day and the day of the week; in-network or roaming, etc, complicating price comparisons. But by the mid-1990s, competitive and technological forces combined to make mobile communication a mass-market service in which budget conscious consumers had more options. Pre-paid cards eliminating the need for a long-term contract (or to provide identification, pass a credit check, etc.) were introduced in 1994. For those not minding the lock-in of a contract, bare-bones "road-side assistance" plans could be had for $15/month, or springing for more minutes, a basic phone could be thrown in for free [Federal Communications Commission, 1997].

[16]Since the 1970s, a new version of the radio had been developed. It looked like a phone and could be rigged to connect to the regular phone system.

[17]Using the CPI.

In 1994, the retail price per minute started to drop after years of little sign of change [Hazlett, 1999, figure 2]. In terms of contract expenditures, the average local monthly bill dropped from $95 in 1988 to $52 in 1995, a level it would maintain through the 2000s (CTIA).[18]

In 1998 cellular telephony was common enough to be included in the CPI [Hausman, 1999], and around year 2000 the subscription base reached the 100-million mark, or roughly one subscription per household.[19]

Expansion continued apace in the 2000s, in no small part driven by the introduction of smart phones, demand for basic voice and text services having plateaued. The first camera phone appeared in 2000. Full Web browsing arrived in 2003 (the BlackBerry 7230). The iPhone ushered in the mainstreaming of data capability in 2007. The term "burner phone" (circa 2002) illustrates both the usefulness of mobile voice and text functions for illegal activities as well as the near disposability of what was once a luxury item.

Our hypothesis is about cheap mobile two-way communication, whether by SMRs, PCSs, or cellular telephony. This category could include pagers but we think pagers were less important for our hypothesis because only souped-up versions provided two-way communication, and only once this service was already offered cheaply by cell phones and its CMRS siblings. Nevertheless a note on pagers is warranted.

Pagers made a brief but noteworthy foray into the mainstream in the 1980s. Pagers were largely limited to one-way, highly abbreviated communication and their popularity in the 1980s speaks volumes about the then state of cell phones. Pagers existed before 1980 but their range had been too limited to provide more than mobile intercom within a work site or similar. In 1980 wide-area pagers with city, even national range were introduced. Additional functionality included ability to display a number and, by the mid 1980s, a brief message.

By the end of the 1980s, the role of pagers in drug distribution was clear to the point of service providers taking counter measures.[20] Unlike the cell phones of their time, they were affordable enough to make their way into high schools where they conferred a certain status on their carriers.[21]

However, pager use seems to not have changed the final leg in drug distribution, its use appears to have been limited to communication between dealer and provider and up the distribution chain.[22] Why that was can be speculated about, but perhaps the one-way and highly limited amount of information that could be communicated kept pagers from affecting the turf-based street dealing drug trade.

[18] http://files.ctia.org/pdf/CTIA_Survey_MY_2012_Graphics-_final.pdf

[19] The Wireless Association https://www.ctia.org

[20] Jim Schachter. "Paging Service Hopes Surcharge Gives Drug Dealers the Message" LA Times October 06, 1988,
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[22] Tibbets, Wendy. "Technology: What was it like when people used beepers and not cell phones?" July 5, 2017.
https://www.quora.com/Technology-What-was-it-like-when-people-used-beepers-and-not-cell-phones

2.2 Illegal Drug Dealing

Illegal drugs, like any other product, reaches the end user via a manufacturer-wholesaler-retailer-end user chain. Our hypothesis concerns the last leg. Johnson [2003] identified three types of markets for end users: public network, private networks, and freelance public distribution. Wrote Johnson [2003, page 4]: "Public networks involve sellers and lower-level distributors making sales to buyers in public settings (streets, parks) and even in private spaces (bars, clubs, stores, hallways and common areas of buildings). Buyers/sellers rarely know each other personally."

The spread of cell phones undermined the public network market, we propose. It is the most visible of the markets and the possibly the most violent prone. Why some types of drug dealing foster violence, while others do not is a subject of some interest considering the possibility that we are presently in a high-drug-use-low-violence regime.

2.2.1 Gangs-Drugs-Violence?

Street or youth gangs had been part of the urban landscape well before the crime waves of the 1980s and 1990s, organizing working-class male youth often along lines of ethnicity or nationality. Activities ranged from socializing to petty crime and occasional street fights with rival gangs. As narcotics use become more common in the 1970s, gangs started to control street dealing. The money making potential in drug dealing quickly outshone those of other activities [Howell and Decker, 1999]. Cue the drug gang, a more moneyed and more violent version of the street gang. Gang membership has since been strongly associated with homicides (e.g., Decker and Curry [2002]), as well as a slate of other crimes (e.g., National Gang Intelligence Center [2013]).

Wrote Johnson et al. [2000, page 180] about the late 1980s:

> So many people were striving to make "crazy money" that competition among sellers was the major problem. ... The more-organized crack sellers introduced a variety of violent innovations to control competition and increase their profits. Crew leaders started to hire a "protector" to defend turf and enforce sanctions against operatives. Many of these muscle men were perceived as "crazy," or unpredictably violent, which enhanced their image, instilled fear in others, and increased their worth. ... [juveniles] quickly learned of enhanced job opportunities associated with acting crazy. ... One of the most effective tactics towards this end was to talk about, display, or use guns.'

But why are drug gangs violent to start with? Illegality and profitability emerge as key factors, dimensions we now turn to.

To start with illegality, the cost-benefit calculation of an illegal organization favors violence because the costs are lower and the benefits are higher. Legality offers a number of benefits, including protection against confiscation of property and access to judicial recourse. Use of violence is one way to lose legal status, a margin only relevant for legal enterprises.[23] Thus the cost of violence is higher for legal than illegal outfits.

As for the benefits, violence is one way to enforce property rights and settle conflicts particularly attractive to illegal organizations. While legal organizations tend to favor

[23]Non-State combatants pose a direct threat to the State and it is therefore unsurprising that private armies, militias, even duelling [Tilly, 1990] are highly circumscribed in modern states.

contractual obligations and third party enforcement, notably by courts, this avenue is fraught with difficulties for the illegal organization. Courts, in the Western tradition, are loath to enforce contracts on illegal activities. Furthermore, courts lean heavily on written contracts, documents the illegal organization tends to avoid since they constitute prime evidence against it [Reuter, 1985].

Thus, the cost-benefit calculation for violence looks better for illegal than legal organizations. Still, not all illegal organizations use violence pointing to additional considerations, a matter of interest to us since we argue that homicides fell because of changes to the retailing of illicit drugs.[24]

Profits, territoriality, and ambiguity are additional factors. Since the State has an obvious interest in curbing lethal violence and also has considerable resources at its disposal, organizations will only resort to lethal violence if the profits from so doing are high.[25] Drug selling, especially if cartelized, can provide such profits.

Territory dependent profits, the case in turf-based drug dealing, fans violence because territory is physical space that can be attacked or defended.

Lastly, a level of ambiguity is required. If an outcome is certain, then the parties can economize on the fighting. Periods of uncertainty, for instance because of a weak(ened) incumbent (e.g., Dell [2015]), may trigger violence. In terms of market entry, the in-between case may be more conducive to violence than the extremes: secure monopoly (e.g., Bertoloai and Scorzafave [2018]) or free entry (the case considered here).

In sum, drug dealing in the US in the 1980s and early 1990s exhibited all four features conducive to lethal violence: illegality, profitability, territoriality and ambiguity. This situation may have come to an end with the mainstreaming of cell phones. The cell phone allows buyers and sellers to make contact and improvise on the point of exchange, rendering redundant the fixed market place. In the 1990s, in particular in the later half, cell phones became affordable enough to be everyday possessions. Interestingly, in 1997, a New York Times article noted that drug dealing had moved indoors.[26]

If cellular telephony freed sellers from the need for turf access, then the lower barriers to entry should have resulted in lower drug prices. In fact, prices fell. In 1990, a gram of heroin cost about $300 (inflation adjusted to 2015$), today it can be had for a third of that.[27] Further, the price decline was steepest in the 1994-2001 period.[28]

Lower prices suggest squeezed profit margins, reduced gang income and with it the appeal of gangs. While gang activity is difficult to measure, it appears that after a prolonged period of steady increase [Miller, 2001], youth gang membership declined through the later half of the 1990s and held steady between 2000 and 2012 (latest year available).[29] Furthermore, youth gangs may have assumed a less crime-oriented identity, for instance, by being more inclusive and less cohesive than in the past [Pyrooz and Sweeten, 2015, Morselli et al., 2017].

[24]For anectdotal evidence, see e.g., Miroff, Nick "Mexican traffickers making New York a hub for lucrative – and deadly – fentanyl." *Washington Post* 13 November 2017.

[25]In addition to attracting the attention of law enforcement, violence creates bad-will in the affected communities, deters customers, and demoralizes the rank and file [Levitt and Venkatesh, 2000].

[26]Rohde, David. "Where Has Your Neighborhood Drug Dealer Gone?" *The New York Times* 17 August 1997.

[27]*Washington Post*, August 27, 2015: "Why a bag of heroin costs less than a pack of cigarettes."

[28]United Nations, reported in "Heroin Prices" *The Economist* 25 June 2009.

[29]National Youth Gang Survey Analysis `https://www.nationalgangcenter.gov/survey-analysis/measuring-the-extent-of-gang-problems`

3 Empirical Strategy

We estimate a regression model of the following form:

$$HOMI_{ct} = ANT_{ct} + \alpha_c + \alpha_t + \epsilon_{ct}, \qquad (1)$$

where:
$HOMI_{ct}$ – Homicides per 100,000 inhabitants in county c and year t.
ANT_{ct} – Antenna structure density in county c and year t.
α_c, α_t – county and year fixed effects.

In our preferred specification, regressions are population weighted and standard errors are clustered at the county level. Year fixed effects control for common time effects across counties. County fixed effects control for time-invariant county characteristics, such as pre-existing infrastructure or demographic profile. We also introduce location-specific time trends (county- specific quadratic time trends, or CSA-year fixed effects, as the sub-sample allows for).

This approach explores *within* county variation in antenna structure under the assumption that the *timing* of the build-out is unrelated to other determinants of homicides. However, cell network expansion was clearly not random. For instance, population density clearly played a role in placement. It is also quite conceivable that areas with more economic activity, or slated for such, saw greater infrastructure investments. Alternatively, better infrastructure could attract new firms and change the employment prospects of the local population, or the local population itself, with attendant consequences for crime (e.g., Dix-Carneiro et al. [Forthcoming]). There could also be an affect on crime through the effects of cheaper and easier to obtain drugs.

Here, the 1970s may prove instructive: between 1973 and 1982, there was network expansion in preparation for cellular service, but no service. Assuming that the relationship between antenna structure placement and economic activity was the same in the 1970s as the other decades, the 1970s could serve as a "placebo" period. No effect on homicides in this period would support the case for antenna structure build out being unrelated to other determinants of violence.

Another tack is to examine the exogeneity of antenna structure placement to county indicators of economic activity. We will focus on county OD deaths and the employment rate. Under our hypothesis, more antennas should have made drugs cheaper and easier to obtain and to the extent that higher drug use (as opposed to profits in drug dealing) lead to homicides, omitting a measure of drug use goes against us. The employment rate proxies for the economic environment. If antennas were put in place in economically more successful areas, this could introduce a spurious negative association between antennas and homicides.

4 Data

We draw on two main sources, the FCC's register of antenna structures[30] and Vital Statistics mortality files. We supplement the mortality data with FBI's Supplementary Homicide Reports. We aggregate the individual-level data to the county level.

[30] http://wireless.fcc.gov/uls/index.htm?job=transaction&page=weekly

We restrict the study to the contiguous United States and the years 1970-2009 (data are missing for 1989). These four decades cover the rise and decline in crime as well as many signature dates in the development of cellular telephony. The end year falls before the emergence of the "Silk Road" and other darknet sites as well as the proliferation of synthetic opioids.

Our analysis sample has some 120 thousand county-year observations. There were 3,118 counties or county equivalents in the contiguous US (in 2016). For the 1990s, our focal decade, we capture 3,100 or more of these counties, the missing counties being rural with small populations.

4.1 Homicide

The United States uses two national data collection systems to track detailed information on homicides: the Federal Bureau of Investigations's Supplementary Homicide Reports (SHR) and the National Vital Statistics System (NVSS) [Bureau of Justice Statistics, 2014].[31]

The NVSS data draw on death certificates and are maintained by the National Center for Health Statistics (NCHS), and we will reference this agency, or simply vital statistics when referring to the mortality files. The NCHS data contain information on the date and cause of death.[32] Reporting of deaths is mandatory. However, in the absence of witnesses or clear evidence as to the circumstances of the death, the homicide classification is a judgement call [Bureau of Justice Statistics, 2014].[33]

The public-use files include county (occurrence or residence) identifiers for all counties prior to 1990. For the years 1990 and onwards, we use the restricted-use data with county identifiers for all counties.[34] We use the county of occurrence and limit the sample to US residents.

Additional contextual information can be had from the Supplementary Homicide Reports (SHR), part of the FBI's Uniform Crime Reporting (UCR) Program. Notably, the SHR provide information on the apparent circumstances and the victim-offender relationship.[35] The data are at the incident level and reported by individual policy agencies on a monthly basis. As detailed by Maltz [1999], this additional granularity comes at a cost. Agency participation is voluntary and policy departments vary in the priority given to filing. Many agencies fail to report for all or some months of the year. Among those that report, there is variability in diligence. For instance, all homicides in one city may be linked to drugs, whereas another city reports none, both at variance with the statistically possible. Further, while the circumstances surrounding a homicide can be legitimately unknowable, the "undetermined" category is large and probably contains "determinable" cases.

[31] National Center for Health Statistics. Mortality Data File for 1990-2014 with all county identfiers, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program.

[32] We omit year 1989 because for this year, only a subset of counties are reported.

[33] The number of homicides reported by the NCHS is higher than that reported by the FBI. The main difference is that the FBI, being interested in crime, excludes justifiable homicides (e.g., by law enforcement or by civilians in self defense).

[34] After 1990, only counties with more than 100,000 population are identified in the public-use files.

[35] The SHR captures death by the location of the offence.

4.2 Illicit Drug Use

The NCHS mortality data also offers a measure of illicit drug use, overdose (OD) deaths. Overdose deaths are coded as death by "poisoning by medical or biological substances, whether intentional, accidental or homicide." We follow Ruhm [2016, table 1]'s coding of ICD-10 cause-of-death codes.[36] The ICD-10 code has been used since 1999. For earlier years, cause of death was recorded using ICD-8 (1970-1978) and ICD-9 (1979-1998), and we code cause of death in these earlier years to align with the ICD-10 coding.

As a snapshot of contemporaneous drug use, mortality data have some obvious drawbacks. First, while habitual consumption of illicit drugs trends fatal, use may be ongoing for many years making overdose deaths a lagging indicator. Second, inconsistent potency of a drug tends to raise fatality rates as illustrated by the deadliness of synthetic opioids such as fentanyl and carfentanyl. Third, not all overdose deaths are caused by illicitly obtained drugs, viz. legally obtained prescription drugs [Ruhm, 2018]. Fourth, the OD classification may depend on the results of a toxicology test and there is no national standard for when such is to be performed, thus reporting varies by time and jurisdiction [Seth et al., 2018]. Still, overdose deaths may be the best nationwide county-year measure of illicit drug use available for the study period.

4.3 Antenna Structure Density

A cellular network is made up of cells, each consisting of a base station and antennas mounted on a structure, for instance a tower or a mast. If the antenna structure rises more than 200ft above ground or is within sight of an airport, it needs to be registered with the FCC.

The FCC register contains information on location (coordinates) and year of construction. It also gives height above ground, which allows us to filter out low antenna structures (otherwise, areas close to airports would appear more antenna structure dense without that necessarily being the case). To calculate county density (structures per 1,000 square miles of county land area), we match the antenna structures to counties using Census information on county centroids.[37]

The antenna structures were assigned to counties as follows. First, each structure was assigned to the closest county (centroid) as well as any county within 20 miles. Then, the number of structures assigned to a county was summed, where structures assigned to multiple counties were partially counted (an antenna structure assigned to n counties was counted as $1/n$ in each county). Considering the finite capacity of antenna structures (and antennas), we think this is a reasonable assignment.

To obtain a density measure, we divide the number of antenna structures by the county land area.

For time variation in antenna structure density, we use the year of construction. That is, once constructed, we assume that the structure stays there. While this may not be literally true, the study period was one of expansion.

For ease of exposition, we will occasionally let "antennas" substitute for "antenna structure density."

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[36] That is, All Drug Poisoning Deaths, ICD-10: X40-44, X60-64, X85, Y10-14. We do not include, Y35.2 (legal intervention), or *U01.6, *U01.7 (terrorism).

[37] County centroid and land area information as of year 2000, `http://www.census.gov/tiger/tms/gazetteer/county2k.txt`.

While we proxy cell-phone uptake by density of registered antenna structures, a number of caveats are worth bearing in mind. First, antennas have a number of uses (tv, radio, public safety radio communication). We do not know which one(s) an antenna structure was used for. Still, by 1973, the above were mature technologies with high level of penetration and therefore to a first approximation, expansion since 1973 largely reflects the growth of CMRS.

Second, the relationship between structures and service is not constant. Initially, towers were built and operated by individual phone companies. The 2000s see the emergence of independent tower companies that lease out antenna space, allowing one tower to serve several networks.

Third, the FCC registry covers only towers rising 200ft or more above ground (or within sight of an airport). Over time, the cells making up the cellular network have become smaller, thus lowering the height demands of antenna structures. This development accelerated in the 2010s (outside our study period).

4.4 Combined Statistical Areas – CSAs

Our hypothesis primarily concerns urban violence, turf requiring some population density. Therefore, we are interested in grouping counties by a measure of urbanicity. In addition, we are interested in grouping counties belonging to the same metropolitan area to control for common economic shocks. To these ends, we use the Combined Statistical Area typology, the Census states: "Combined statistical areas (CSA) consist of two or more adjacent metropolitan and micropolitan statistical areas that have substantial employment interchange."

Using the year 2013 classification, there were 166 CSAs in the contiguous United States. The New York-Newark CSA (population 23 million) was the largest CSA, followed by Los Angeles-Long Beach and Chicago-Naperville. The smallest CSA was Steamboat Springs-Craig, CO (population 37,757, 2016 estimate).

CSAs counties are more urban than non-CSA counties by defintion, a fact also reflected in the population statistics. While only about 37% of counties belong to a CSA, these counties account for about 75% of the population (in the contiguous USA).

On average, there were about seven counties per CSA. To further zero in on urbanicity, we designate the county containing the main Central Business District (CBD) of the CSA as "main." Many CSAs contain multiple cities or towns, and we give the main designation to the CBD county of the first named locality. For instance, for the New York-Newark CSA, New York City is named first and Manhattan contains the CBD, thus Manhattan is the main county. In a handful of cases, the CBD abutted two or more counties, in which case they were all given the "main" designation.[38]

5 Analysis

We start the analysis with some descriptives. Figures 3-6 show the decadal change in antenna density by county. Table 2 details these changes by county urbanicity. Clearly, the 1990s is the decade with the most expansion. Overall, (population weighted) antenna

[38] For the list of CSA names, see `https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/bulletins/2017/b-17-01.pdf`.

density increased from 14.6 to 22.9 antennas (per 1,000 square miles). The increase was higher in urban areas. Among CSA counties, antenna density increased from 17.3 to 26.7, whereas among the main CSA counties the increase was from 20.1 to 30.2.

Meanwhile, homicide rates dropped from 11 (per 100,000 population) in 1990 to 6.2 in 2000, a decline of 4.8. Broken down by urbanicity, the respective numbers for CSA counties were 11.9 and 6.5, a decline of 5.4 homicides (per 100,000 population). For main CSA counties, homicides rates fell from 17.3 to 9.5 between 1990 and 2000, a reduction of almost eight homicides.

Our hypothesis turns on a change in the relationship between drug dealing and violence. Figure 7 reports the correlation between homicides and overdose deaths (conditional on county fixed effects) by year for the period 1970-2009. We see that from the mid-1970s to the mid-1990s, the correlation was positive and rose with the overdose death rates, consistent with the homicide waves around 1980 and 1990 (Figure 2) being drug-use related. Before that period, OD rates were low and so was the correlation with homicides, again supportive of homicide rates being drug related. After the mid-1990s, however, the relationship breaks down. OD deaths are high and rising but the correlation with homicides falls and fails to be statistically significance, consistent with our hypothesized trend break.

We now turn to the regression analysis.

5.1 Regression Results

Table 3 shows the results from estimating variations of Equation 1 on the full sample (counties in the contiguous US, years 1970-2009, except 1989). Simply regressing homicide on antennas yields a positive relationship, contrary to our hypothesis (Column 1). The positive association is strengthened by the inclusion of year fixed effects (Column 2) but turns negative once county fixed effects are included (Column 3). The addition of county-decade fixed effects strengthens the negative relationship (Column 4) and the estimated effect maintains significance once the standard errors are clustered at the county level (Column 5).

We next present results from alternative ways of computing antenna density and the results remain similar. Column 6 shows the results from simply summing antennas assigned to a county (subject to rising 200ft above ground). This raises the antenna density substantially and likely more so for urban counties. This measure performs equally well as the "share" measure used in Columns 1-5.

Column 7 dispenses with the height restriction and include all registered antennas irrespective of height above ground. Since antenna structures rising less than 200ft above ground only need to be registered if close to an airport, removing the height restriction raises antenna density in counties with airports. As expected, this cruder way of computing antenna density results in a less precise coefficient estimate.

As mentioned, there is likely substantial decadal heterogeneity in the relationship between antennas and homicides. In the 1970s towers were constructed but there was no cellular service. In the 1980s, the service existed, but it was expensive and phones were bulky and mono-functional. It is not until the 1990s that we expect cell phones to have a meaningful impact on drug retailing.

Table 4 uses our preferred specification (i.e., Column 5, Table 3) to look at subsamples by decade and by county type. To start with the decadal breakdown. Consistent with our hypothesis, the coefficient in the 1970s is highly insignificant (Column 1). The coefficient is negative in the 1980s and is borderline significant. Fast forward to the 2000s, the estimated coefficient is close to zero. By contrast, for the 1990s, the estimated coefficient is negative and statistically significant at the 5 percent level.

We expect the effect to be stronger in more densely populated areas and Columns 5-7 confirm this to be the case. The estimated effect is larger and is estimated with greater precision in the main CSA counties (Column 5) compared to all CSA counties (Column 6). In rural (non-CSA) counties, the estimated effect is not significant (Column 7).

5.2 CSA counties, 1990s

As hypothesized, the results were stronger in more urban counties and in the 1990s, and the continued analysis will focus on this subset: CSA counties and the 1990s.

Table 5, Panel A, Columns 1 and 2 restrict the sample to the main CSA counties. In Column 1 we see that results remain negative and significant. Adding CSA-specific quadratic time trends (Column 2) substantially reduces the coefficient estimate (but raises precision). The attenuation is perhaps not surprising considering that in only a handful of cases do we have more than one county per CSA.

In Columns 3-5, we expand the sample to all CSA counties, which allows us to include CSA-specific year fixed effects. Interestingly, inclusion of CSA-specific year controls (quadratic time trend or year fixed effects) do not reduce the point estimate, which is about 70% of that estimated for main CSA counties (Column 1). Antenna structure density in CSA counties went from 17.3 to 26.7, an increase of 9.4. An estimated coefficient of -0.154 thus implies a difference of 1.45 homicides per 100,000 population in CSA counties comparing year 2000 to year 1990, or 26% of the observed decline in these counties (which at 200 million accounted for 75% of the population in the contiguous USA, mid 1990s). Translated into homicides per year, this represents a reduction of 2,900(=1.45$\times$2,000) homicides or about 30% of the 9,897 drop between 1990 and 2000.[39]

It is possible that our results are confounded by factors that were affected by antenna structure density. Infrastructure could plausibly be targeting economically more promising areas, or beefed up infrastructure could boost economic activity, which in turn could impact homicide rates. Therefore, in Panel B. we let the county employment rate be the dependent variable. We expect antennas to be positively correlated with economic activity and thus employment levels, which in turn could reduce homicide rates (e.g., [Dix-Carneiro et al., Forthcoming]) and thus form a potential confounder. However, contrary to our expectations, results indicate a negative and insignificant association, except for the Column 2 specification – sample restricted to main CSA counties and including CSA-specific time trends.

Another possible confounder is that antenna structures and cell phone mainstreaming should have made illicit drugs cheaper and easier to obtain, factors that typically would increase drug use. Greater drug use in turn could raise homicide rates, for instance from psychopharmacological effects or the erosion of social networks.

Results from substituting the county overdose rate for the dependent variable are shown in Panel C. The only statistically significant result obtains in the main CSA county

[39]For the contiguous US. The vital statistics show 27,218 homicides for 1990 and 17,321 homicides for 2000. These numbers are higher than those reported by the FBI because *inter alia* FBI statistics exclude justifiable homicides (e.g., self defense or defense of others).

sample and the specification including CSA-specific time trends (Panel C, Column 2). Taken at face value, this result goes against us.

In sum, potential confounders go against us or fail to reach statistical significance.

Race and Age So far we have ignored demographics, but gang violence tends to prey on its own. The National Youth Gang Survey (1996-2011) estimated that 40-50% of gang members to be juveniles (under 18); more than 90% male, and about 80% Black or Latino/Hispanic.[40] Therefore, we now turn to breakdowns by age and race, focusing on males. We focus on two groups, Black or Hispanic, and non-hispanic White.[41]

For reasons of sample size, we focus on five-year age bins between ages 15 and 39. Since we are looking at a rather rare event, we restrict the sample to county-year observations with more than 100 males in the relevant age and race cell.[42]

Figure 8 presents the coefficients and 95% confidence intervals from estimating the equivalent of Table 5, Column 5 specification on race by age sub-samples. We see that the estimated coefficients are consistently negative for Blacks or Hispanics whereas for Whites, the estimated effects are close to zero and only statistically significant for the 15-19 age group.

5.2.1 Homicide Context

Our hypothesis suggests that types of homicides more closely related to drugs or gangs would be more affected by cell phone mainstreaming. To that end, we turn to the FBI's Supplementary Homicide Reports which reports the circumstance and the victim-offender relationship.

In addition to drug dealing, crimes found to have high street-gang involvement include assault, robbery, and threats/intimidation [National Gang Intelligence Center, 2013, page 14]. Therefore homicides with such mentions are of particular interest to us. As for victim-offender relationship, we expect killings by strangers to be more affected than, say for instance, employer-employee killings or spousal murder (gang members not being the marrying type).

Before going into the results, a note on coverage is warranted. Unlike the vital statistics data, SHR reporting is voluntary. Notable absences for part or whole of the 1990s are DC, Florida, and Louisiana, the homes of "high crime" cities such as DC, Miami and New Orleans. Missing counties and partial reporting from counties means that for our sample covering the 1990s and CSA counties, the SHR covered homicides amounted to about half of homicides reported in the Vital Statistics.

Partial reporting raises the question what population denominator to use when calculating rates. The SHR provides reporting agency population figures, but unfortunately this information is zero or missing in a non-trivial number of cases. Therefore, in the

[40] National Gang Center. National Youth Gang Survey Analysis. Retrieved March 11, 2018, from `http://www.nationalgangcenter.gov/Survey-Analysis`.

[41] Hispanic status was not reported on the death certificate by Oklahoma (1990-1996), Louisiana (1990) and New Hampshire (1990-1992) for indicated and therefore records for those states and years are excluded. Additionally, decedents whose Hispanic status was stated as unknown were included among the Black or Hispanic group and excluded from the non-Hispanic White group.

[42] We experimented with 100, 200, and 500 cutoffs and found the results to be quite similar, but with drastic effects on sample size. So as to minimize sample selection due to a high cutoff, we choose 100 as our cutoff level. A population of 100 means that if a homicide were to occur, the implied rate per 100,000 population is 1000.

preliminary analysis, we considered three approaches: (i) the county population; (ii) the county aggregate of agency (ORI) populations where missing values were treated as zeros; and (iii) only included counties for which no agency (ORI) reported missing population values. The three approaches resulted in different population counts and analysis samples. However, regression results were very similar across the three approaches.

Therefore, we chose (i), the county population, as it produces the more straightforward sample: counties with at least one agency reporting to the SHR. These "SHR-reporting" counties form the universe for our analysis of the SHR information on homicide by context (Tables 6-8).

Circumstances Figure 9 shows the series of homicides (counts) grouped into five broad categories: Narcotics-Gang, Argument, Theft, Miscellaneous and Undetermined. These five groups move with remarkably synchronicity in the 1990s, but arguably the first three are more related to drugs and gangs.

Narcotics-Gang groups circumstances explicitly mentioning drugs or gangs (for the list of the specified circumstances, see Appendix Table A1).

Arguments is the single most common category and while somewhat generic, gang culture may be one reason arguments turn deadly. As mentioned, gang culture is characterized by a weaponized environment in which toughness is feted [Johnson et al., 2000, Levitt and Venkatesh, 2000, Johnson, 2003] and minor incidents can escalate [Sethi and O'Flaherty, 2010].

Theft is the third category of interest, it covers robbery, theft and larceny. As noted, gangs are crime generalists, drug sellers can make for attractive robbery targets, and theft is one way for addicts to finance their addiction.

These three groups accounted for almost half of the homicides covered by the SHR. Remaining homicides can be split into two roughly equal sized groups: Miscellaneous and Undetermined. The circumstances grouped under Miscellaneous had less of a clear link to drugs or gangs, examples include "brawl due to influence of alcohol," "lovers triangle," "victim shot in hunting accident."

Since the SHR does not cover all counties, we start by replicating the results of Table 5, Panel A for the SHR-reporting counties using the NCHS homicide data. We see that results also hold in this sub-sample. Although effect sizes are smaller, coefficient signs go in the same direction and reach statistical significance, confirming previous findings.

Turning to homicide circumstance, we see negative and mainly significant estimates of antenna density for the three groups of homicides arguably most closely linked to gangs and drugs: Narcotics-gang, Argument, Theft (Panels B-D). Further, the estimated effect size is the largest for the narcotics-gang related homicides.

By contrast, antennas appear to have no effect on homicides in the Miscellaneous group (Panel E), consistent with our hypothesis.

In Panel F, we consider as the outcome homicides (as reported by the NCHS) without a specified circumstance, either because the SHR reported the circumstance as Undetermined or because the homicide was not covered by the SHR. In other words, the outcome variable in Panel F is the number of homicides reported in Panel A minus homicides reported in Panels B through E. We find no effect, one interpretation of which is that the SHR information on drug and gang related homicides does capture the bulk of such homicides.

Victim-Offender Relationship The early 1990s brought the term super-predators – juvenile gang members with the ruthlessness and moral compass of child soldiers, wrote Dilulio: "They live by the meanest code of the meanest streets, a code that reinforces rather than restrains their violent, hair-trigger mentality. In prison or out, the things that super-predators get by their criminal behavior – sex, drugs, money – are their own immediate rewards. Nothing else matters to them."[43]

The conjured picture of youth capable of indiscriminate violence suggests that gang violence may be particularly related to killings by strangers. Therefore we turn to the victim-offender relationship reported by the SHR. Four broad categories emerge: Strangers (17%), Friends and Acquaintances (32%), Family (15%), and Undetermined (66%) (for the list of specified relationships, see Appendix Table A2). We expect the link to drugs and gangs to be in descending order, highest for strangers. Figure 10a shows the series and again the synchronicity in the 1990s is striking.

Table 7 present regression results, again focusing on the 1990s and the CSA counties. Since looking into finer categories of homicides reduces the incidence, we scale our homicide measure to per 10 million population. The effects for homicide by strangers was arguably the strongest, the estimates remained significant at conventional levels once CSA-level quadratic trends were introduced (Columns 2 and 4), as well as CSA-year specific fixed effects (Column 5). The coefficient estimate in Column 5 suggests that an increase by 10 antennas/1000 square miles reduced murders by strangers by 22 per 10 million population, a 15%(=22/150) reduction of this type of homicide. The estimated effect on homicides in the Friends and Acquaintances group was weaker. The estimated coefficients maintained statistical significance in the face of CSA-level quadratic time trends, but not CSA-year specific fixed effects. The estimated effect size was also smaller, the implied effect of an additional 10 antennas/1000 square miles being around 10%(=29/274). For Family, estimates are more precise, but the effect size is yet smaller. Column 4 suggests that a 10 antenna/1000 square miles increase in antenna structure density would result in 0.7 fewer homicides (per 10 million population), or about a 5%(=7/135) reduction. The largest individual relationship category is Undetermined and we find no effect.

That Strangers would be the group with the most important effect lines up with our expectations. We were, however, surprised to find effects for Family – gang warfare being quite distinct from domestic strife. Therefore, we are interested in taking a closer look at who kills whom within the family. We look at the following groups: spouses, partners, natal family (parents, siblings, offspring) and others (see Figure 10b).

Before going into the result, it may be useful to consider the profile of a typical low-level drug dealer, wrote Johnson [2003]: "Almost no low-level distributors and few sellers pay for their own apartments/home or support a family. In the United States, many lower-level distributors live at severe poverty levels. This is true even when their sales income appears to be substantial," life circumstances perhaps more memorably summarized by "Why do drug dealers live with their moms?"[44] In sum, the typical drug dealer appears to be an unmarried man who has yet to establish an independent household.

Table 8 presents the results, where the first four panels show the results for spouses and partners, and the last two panels show family grouped according to whether natal (parents, siblings, offspring) or others (in-laws, exes, step-children, step-parents, or other family).

[43] Dilulio, John. "The coming of the super-predators" The Weekly Standard, November 27, 1995.
[44] Freakonomics, chapter 3 title.

The largest individual victim category is Wife, and here we find no effect – the point estimate is small and the standard errors are large. In addition to being consistent with the typical drug dealer not being married, this finding is interesting because, as has been noted (e.g., Levitt [2004]), most crime, not just homicides or violent crimes, fell in the 1990s, and looking within homicides, most types of homicides followed the pattern of high rates in the beginning of the 1990s and a sharp drop about 1/3rd into the decade. The pattern for wife (and husband) victims also follow this pattern in the 1990s. Yet, we find no effect of antenna structure density on spousal homicides, consistent with spousal homicides being driven by other factors, e.g., Stevenson and Wolfers [2006]. By contrast, the girlfriend category has seen a steady increase in numbers but we find antennas to have had a tempering effect. (The effects for Boyfriend are weaker and fail to reach statistical significance at conventional levels.)

As for non-partner family, we find effects for natal family members (Panel E), but not other family (Panel F).

Taken together, these results (Table 8) paint a picture of reduced everyday violence by young, unmarried men living at home (possibly from reduced presence of guns around the home, c.f. Evans et al. [2018]). Investigation of victim ages corroborates this picture. The sons and daughters killed were young, the modal victim was an infant. A possible mechanism is that reduced profitability within gangs has lowered the status and return to violence, thereby reducing the presence of handguns in and around the homes of gang members/drug dealers.

6 Discussion

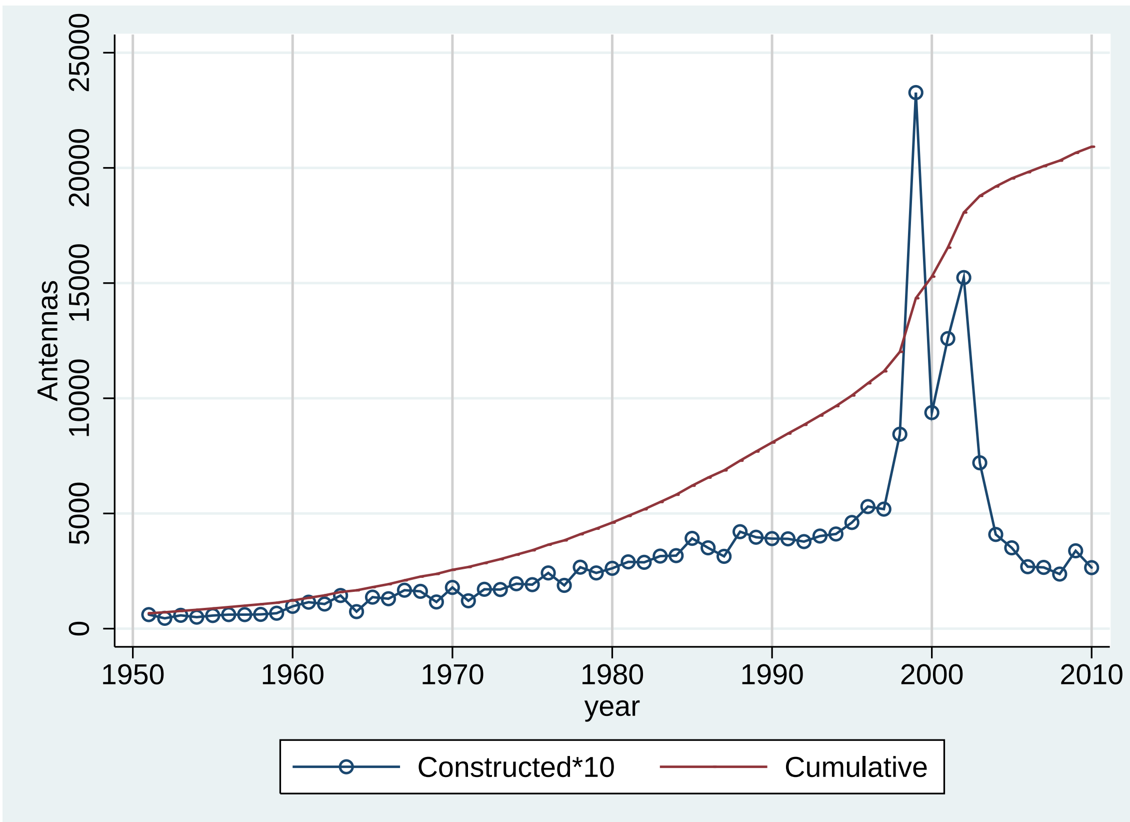
This paper has proposed that cell-phone mainstreaming reduced homicides in the 1990s. Cell phones in the hands of drug users, we argue, reduced gang control of the retail end of illegal drug dealing by making the "turf" redundant. We proxy cell-phone uptake by the build out of cellular phone networks and find that antenna structure density reduced homicides in the 1990s, the decade cell phones went from niche to mainstream. Consistent with cell phones bringing down gang-related violence, we found effects to be confined to urban areas (counties within a Combined Statistical Area), street-dealing being a distinctly urban phenomenon. Furthermore, drilling down on types of homicides we found stronger effects for Black or Hispanic males (victims) and categories of homicides more closely associated with gang violence and drug dealing. By contrast, we found no effect on spousal homicides, a non-finding consistent with low marriage rates among rank-and-file gang members.

Compared to 1990, homicides in 2000 were down by about 10,000 and back-of-the-envelop calculations suggest cell-phone mainstreaming can account for 1,900-2,900 of that decline. The partial nature of our findings is further underlined by the fact that homicide rates today vary substantially across localities. For instance, in 2017, the homicide rate in Baltimore was 55.8 per 100,000 population, or 16 times higher than that of New York City, a difference hardly attributable to differences in cell phone penetration.

The decline (and preceding rise) in violent crime has been a US phenomenon. Our findings point to the circumstances of how illicit drugs are retailed, factors likely to be more salient in the US, arguably the number one consumer market for narcotics, e.g., Peacock et al. [2018].

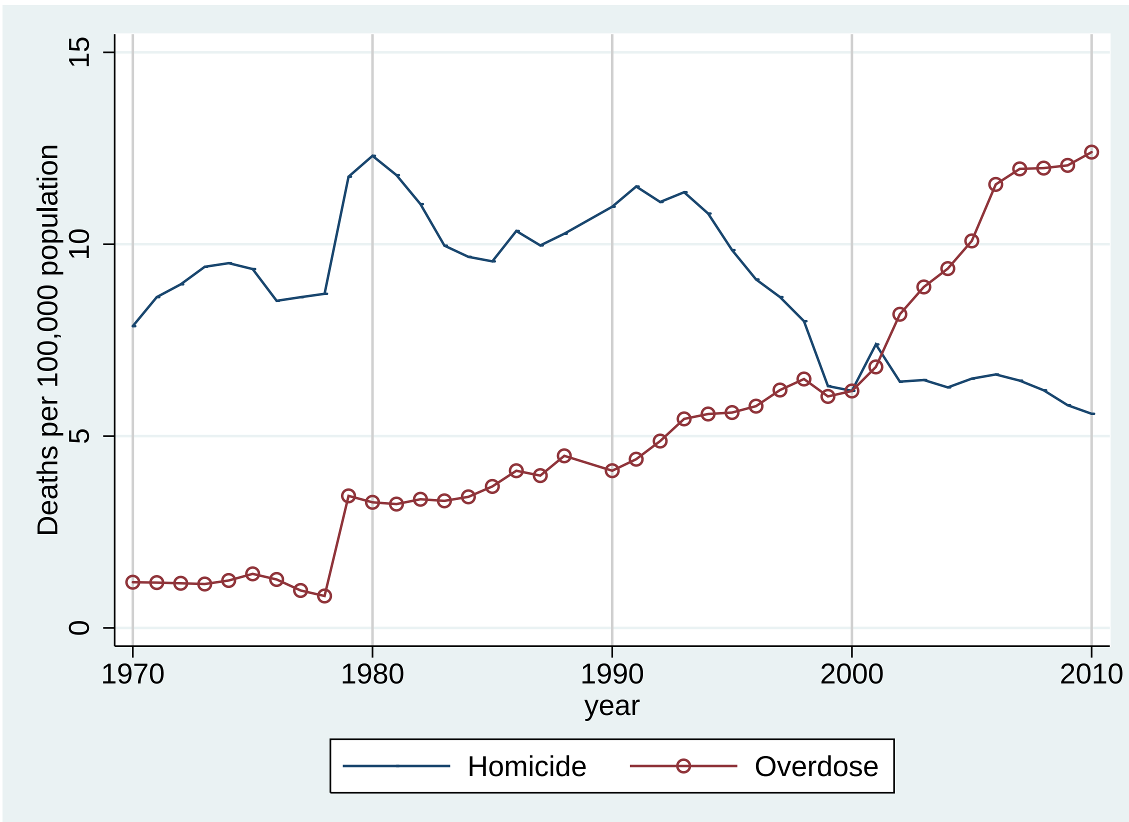
Our findings suggest that cell phones removed a cash cow for US street gangs, increased public safety and reduced prices, many of the advantages touted by advocates of legalization of drugs. Cell phones may also have contributed to an increase in drug use, the scenario feared by opponents of legalization. Thus, cell phones may already have offered a preview of some of the pros and cons of drug legalization.

Figure 1: Antenna Structures > 200ft above ground



Notes: Contiguous USA. Source: FCC.

Figure 2: Homicide and OD Death Rates



Source: NCHS. Notes: Contiguous USA. Data are missing for 1989.
We use vital statistics data which show higher number of homicides than FBI statistics. This is because of different procedures and definitions. By law, a death certificate needs to be filed National Vital Statistics System for each death. In case of homicides this is noted as the cause of death on the death certificate by the medical examiner or coroner. By contrast, the FBI is interested in crime. An investigation may reveal that the killing was justified (e.g., done by law enforcement or civilians in self defense) and these deaths are not part of the FBI statistics.
The jump in OD deaths in 1979 may be associated with the change from ICD-8 to ICD-9 coding. Homicide deaths are less likely to be affected by this change.

Figure 3: Antenna structures (200ft+)/1000 square miles – Change 1970s

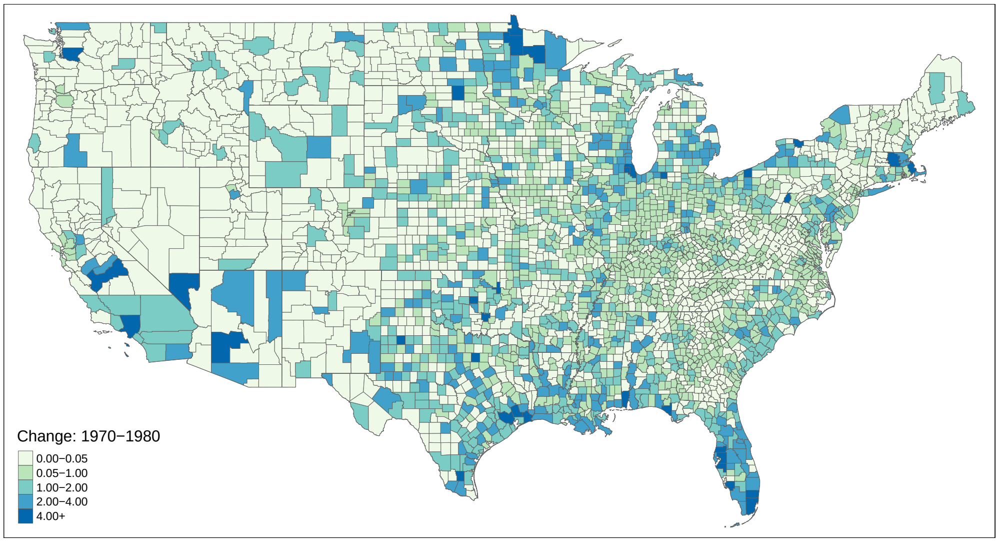


Figure 4: Antenna structures (200ft+)/1000 square miles – Change 1980s

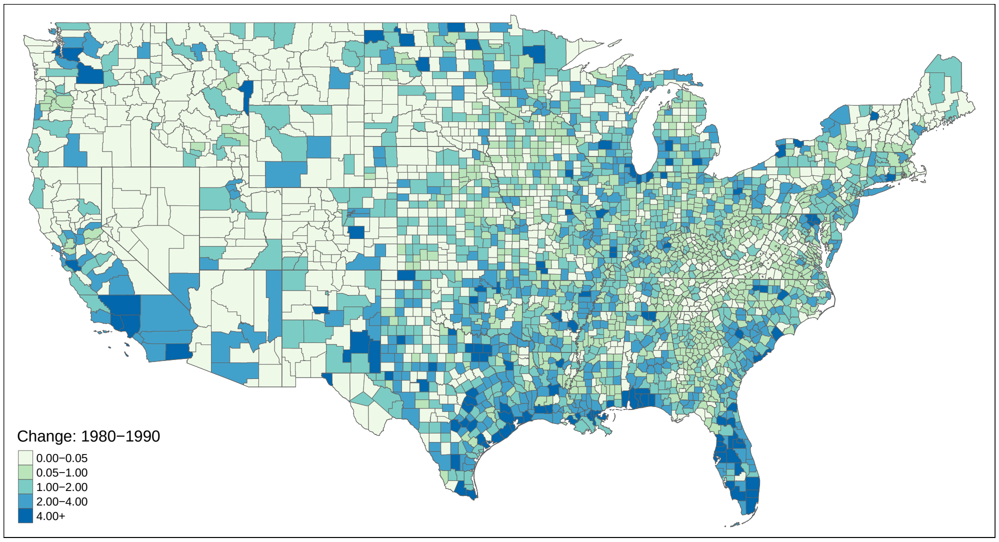


Figure 5: Antenna structures (200ft+)/1000 square miles – Change 1990s

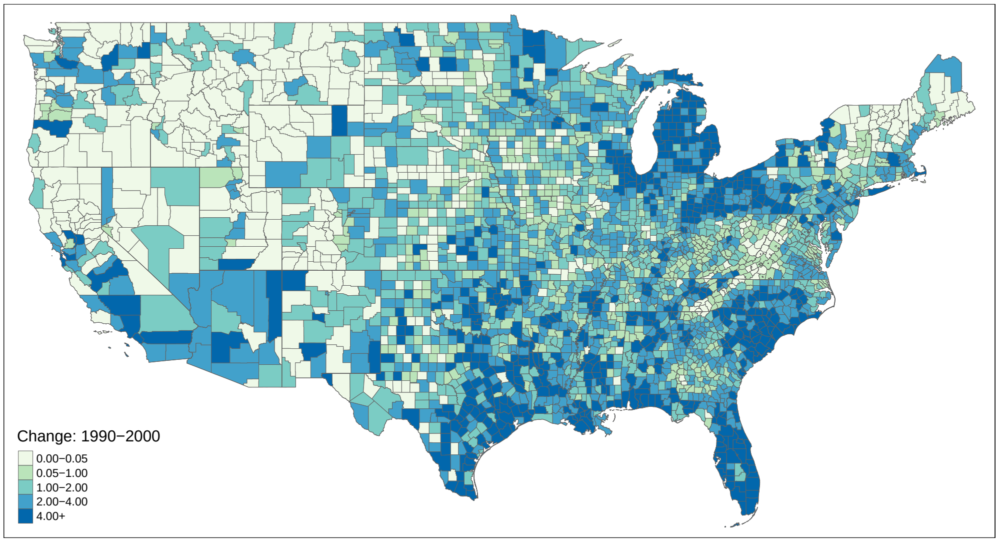


Figure 6: Antenna structures (200ft+)/1000 square miles – Change 2000s

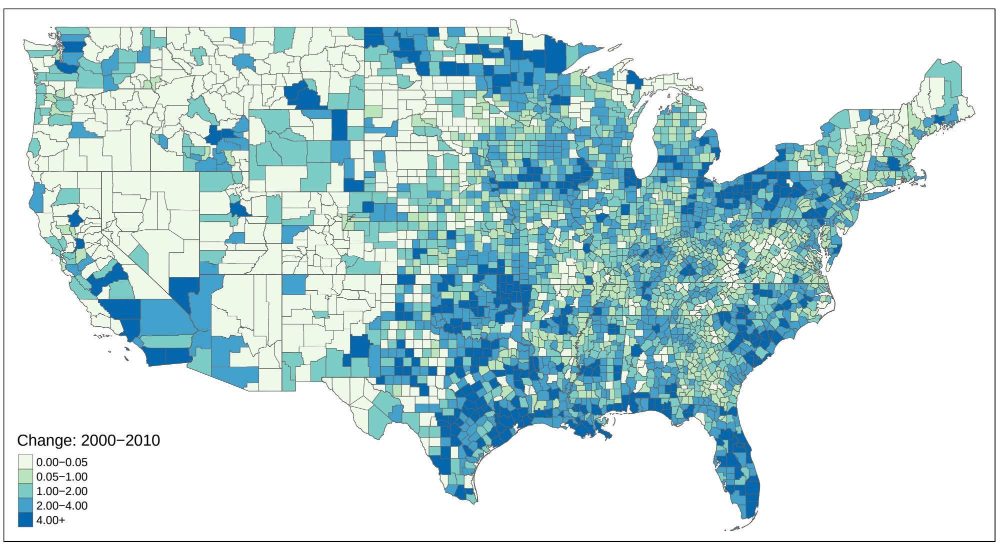
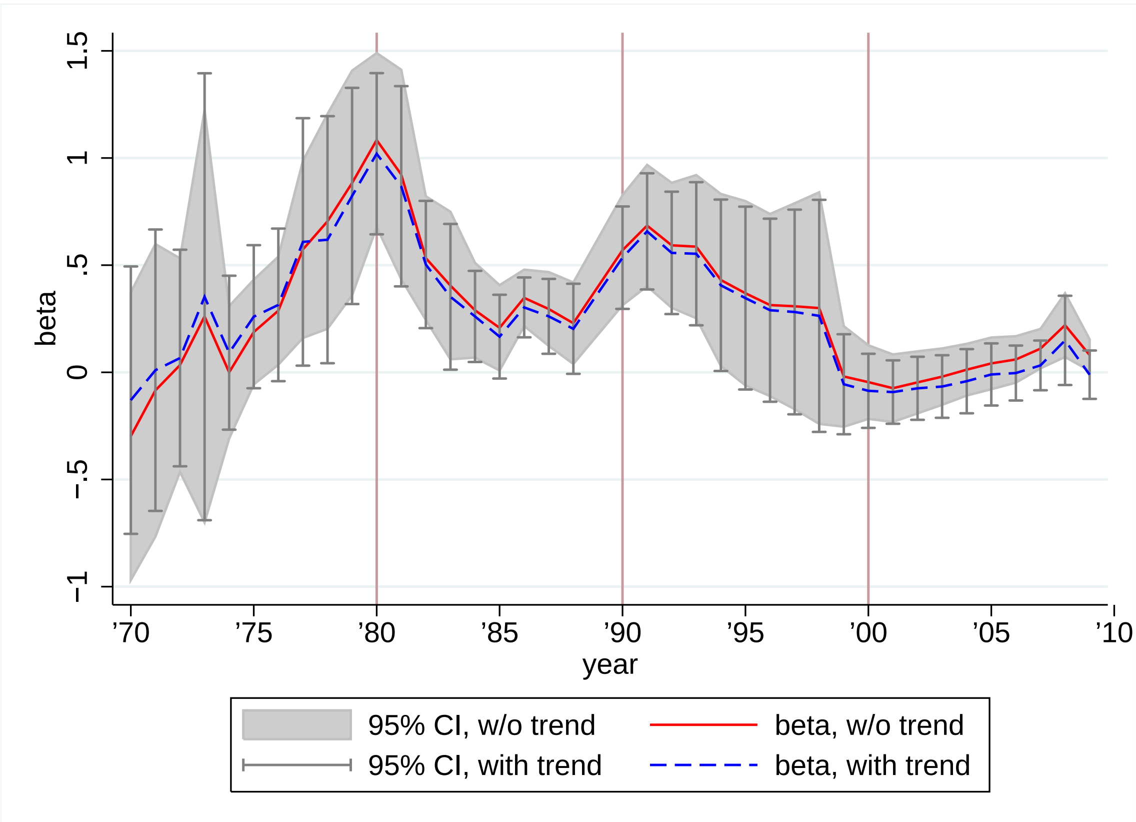
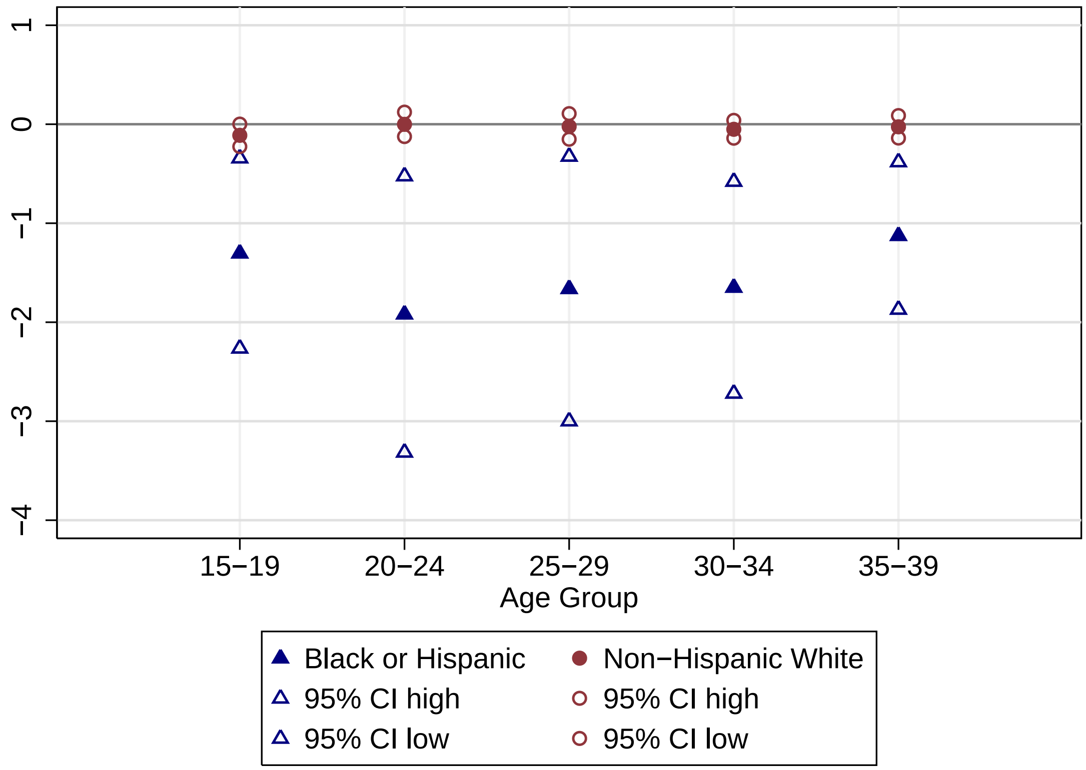


Figure 7: Homicide and Overdose Correlation



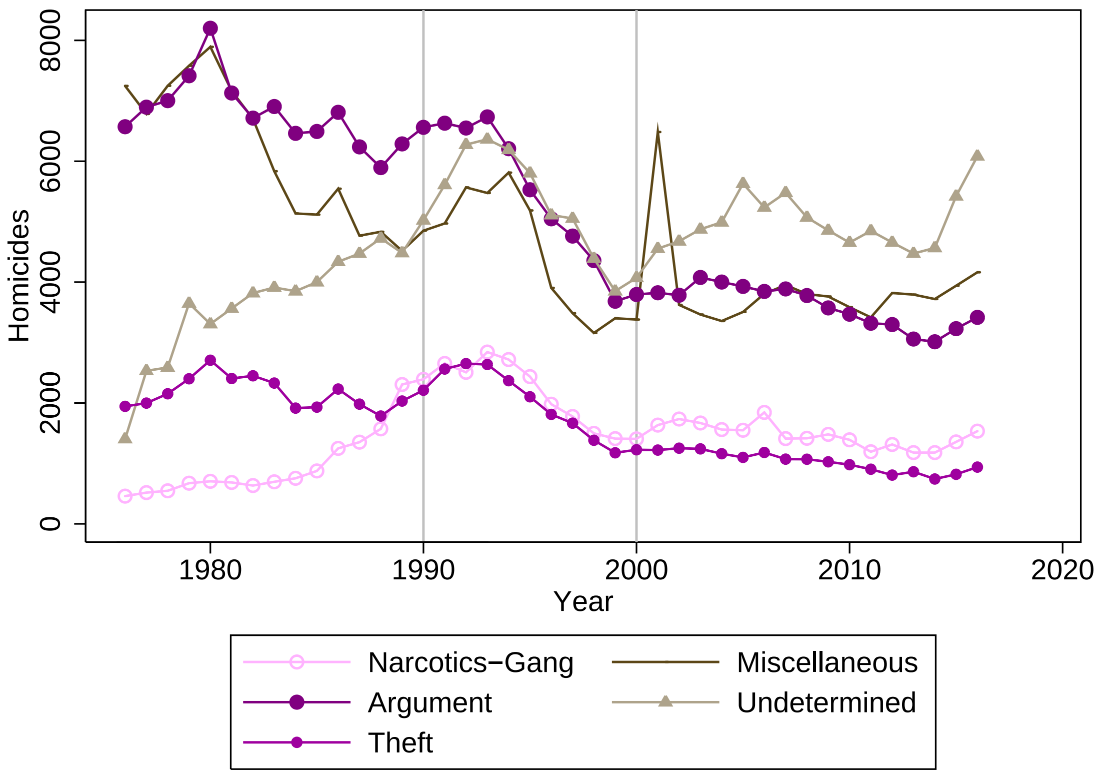
Notes: The figure plots regression coefficients and 95% confidence intervals from regressing county homicide rates on overdose rates, year- and county fixed effects, with and without CSA-specific quadratic trends respectively. The sample is restricted to CSA counties in the contiguous USA. Data are missing for 1989. Source: NCHS.

Figure 8: Effects of Antenna Density on Male Homicide Rates: by Race and Age

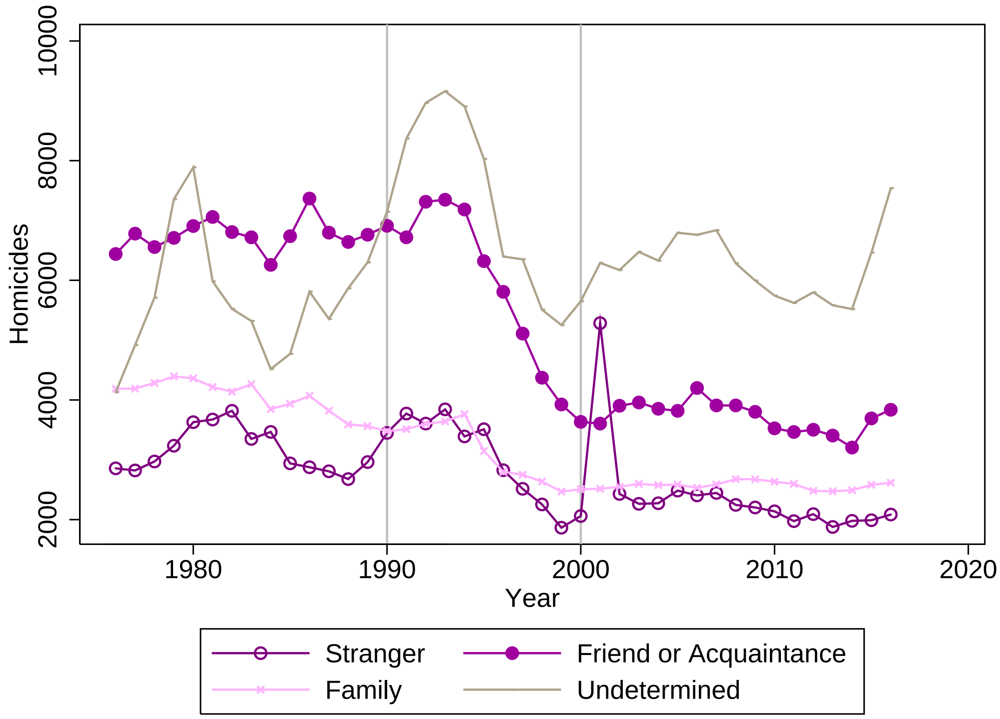


The graph shows the coefficients from the Table 5, Column 5 specification, estimated for the indicated race and age groups. That is, the sample is restricted to the years 1990-1999 and to CSA counties, and the regressions include CSA-specific year fixed effects, county fixed effects and standard errors are clustered at the county level.
The antenna measure is density per 1,000 square mile land mass and the homicide measure is homicides per 100,000 population.
Counties with fewer than 100 men in the relevant age and race/ethnicity group were excluded. The reduction in sample size was greater for Black and/or Hispanic, a group for which the number of county years is reduced from around 11,250 to around 7,250 (varies slightly with age group). For non-hispanic whites, the sample reduction was about 170 county-year observations.
The reason the full sample does not have 11,490 county-years (cf. Table 5) is that following states did not report Hispanic status on the death certificate and are therefore were dropped for the years in parentheses: Louisiana (1990), New Hampshire (1990-1992), Oklahoma (1990-1996).
Black and/or Hispanic includes "hispanic origin unknown."
Non-Hispanic White excludes "hispanic origin unknown."
Source: NCHS.

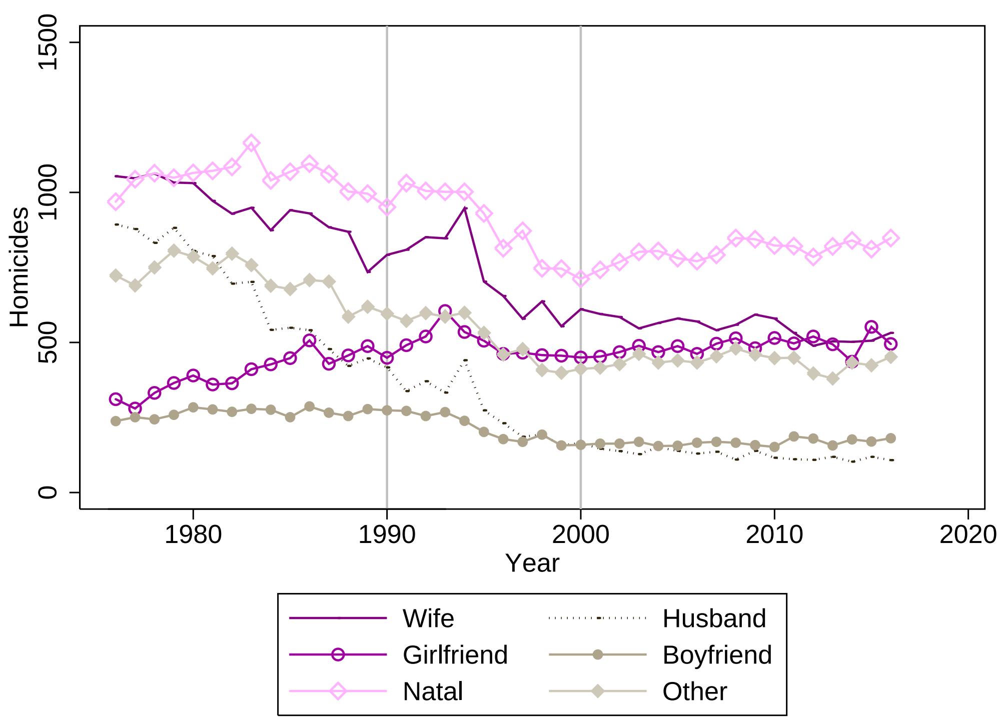
Figure 9: Homicides by Circumstance: 1976-2016



Notes: For a details on the types of circumstances under each heading, please see Table A1.
The 2001 spike reflects the 2,996 victims of the 9/11 attacks.
Source: Kaplan, Jacob. Uniform Crime Reporting (UCR) Program Data: Supplementary Homicide Reports, 1976-2016. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2018-06-19. `https://doi.org/10.3886/E100699V5`



(a) Victim Relation to Offender: 1976-2016



(b) Family Victims: 1976-2016

Figure 10: Homicides by relationship

Notes to Figure 10: For a details on the types of circumstances under each heading, please see Table A2.
The 2001 spike reflects the 2,996 victims of the 9/11 attacks.

Source: Kaplan, Jacob. Uniform Crime Reporting (UCR) Program Data: Supplementary Homicide Reports, 1976-2016. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2018-06-19. https://doi.org/10.3886/E100699V5

Table 1: Key Modern Mobile Telephony Events

Year	Description
1973	First prototype cellular phone call from Midtown Manhattan to Bell Labs, NJ, by Martin Cooper of Motorola
1983	First commercial cellular network opened in Chicago and the Baltimore-DC area.
1991	All digital mobile telephony (2G) launched.
1992	First SMS (short message service).
1993	Omnibus Budget Reconciliation Act reallocates (broadband PCS) spectrum from government to private, commercial use. License winners to be chosen by auction.
	AT&T enters the wireless business with purchase of McCaw Cellular Communications.
	Nextel (previously Fleet Call) on-line L.A. market.
1994	First FCC spectrum auction.
	The Motorola MicroTAC Elite, GSM-compatible and TDMA/Dual-Mode phone introduced. It retailed for around $600 – substantially cheaper than the 1989 version which had retailed at between $2,495 and $3,495.
	First prepaid wireless service introduced by Houston Cellular Telephone Company.
1995	The Nokia 2190 GSM phone was made available on Pacific Bell Mobile Services and Powertel's network.
	Sprint Spectrum – first commercial PCS system – goes on line.
	McCaw invests in Nextel.
1996	Telecommunications Act of 1996.
1998	Cellular telephony included in the CPI.
	First flat-rate plan with national coverage introduced by AT&T: Digital One Rate.
2000	Subscribers pass 100 million mark, up from five million in 1990.
2003	BlackBerry introduces first "smartphone," a phone that could receive and send emails on the go.
2007	iPhone introduced.

Table 2: Mean Antenna Density and Homicide Rates by County Type and Year

	Year				
County type	1970	1980	1990	2000	2010
Main CSA					
Homicide[a]	11.87	19.62	17.27	9.53	8.48
Antenna[b]	9.46	13.63	20.12	30.19	35.81
N	178	179	179	179	179
CSA					
Homicide	8.34	13.34	11.92	6.49	5.84
Antenna	8.42	11.83	17.35	26.66	31.89
N	1142	1144	1149	1149	1148
Not CSA					
Homicide	6.33	9.12	8.01	5.21	4.77
Antenna	1.65	2.98	5.78	10.76	14.49
N	1951	1954	1951	1953	1953
All USA (contig.)					
Homicide	7.87	12.30	10.98	6.18	5.59
Antenna	6.82	9.66	14.57	22.86	27.73
N	3093	3098	3100	3102	3101

Population weighted county means.
[a] – Homicides per 100,000 population. Source: NCHS.
[b] – Sum of antenna structure shares/1000 square miles; antenna structures 200ft or taller within 20 miles of the county centroid; county area is the land area. Source: FCC.
To correct for the some 3,000 homicides in connection to the September 11, 2001 attacks, we replace the homicide counts for Manhattan, Arlington and Somerset County with the average of the flanking years 2000 and 2002.

Table 3: Homicide rate on Antenna Structure Density

	Dependent Variable: Homicide rate Sample: All Counties, 1970-2009 Antenna Structure Measure:						
	Share[a]	Share	Share	Share	Share	Sum[b]	Share-bis[c]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Antennas	0.067***	0.080***	-0.052***	-0.097***	-0.097**	-0.020***	-0.025***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.039)	(0.007)	(0.009)
N	120,930	120,930	120,930	120,930	120,930	120,930	120,930
R^2	0.063	0.134	0.744	0.842	0.842	0.843	0.842
$\bar{y}$	8.754	8.754	8.754	8.754	8.754	8.754	8.754
$\bar{x}$	16.531	16.531	16.531	16.531	16.531	71.397	32.705
Year FE		Yes	Yes	Yes	Yes	Yes	Yes
County FE			Yes				
County-Decade FE				Yes	Yes	Yes	Yes
Cluster					County	County	County

All regressions are population weighted. Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
Year 1989 is missing.
[a] – Sum of antenna structure shares/1000 square miles; antenna structures 200ft or taller within 20 miles of the county centroid; county area is the land area.
[b] – The sum of all antenna structures, 200ft or taller, within 20 miles of the county centroid centroid (per 1000 square mile).
[c] – As for Share, but without height restriction.
To correct for the some 3,000 homicides in connection to the September 11, 2001 attacks, we replace the homicide counts for Manhattan, Arlington and Somerset County with the average of the flanking years 2000 and 2002.

Table 4: Homicides/100,000 Population on Antenna Structure Density

	Dependent Variable: Homicide rate						
	Sample:						
					Counties:		
	1970s	1980s	1990s	2000s	Main CSA	All CSA	Non-CSAs
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Antenna[a]	-0.020	-0.139	-0.151**	-0.001	-0.117***	-0.103**	-0.023
	(0.114)	(0.089)	(0.061)	(0.018)	(0.039)	(0.043)	(0.018)
N	30,955	27,922	31,034	31,019	6,978	44,740	76,190
R^2	0.795	0.847	0.855	0.848	0.899	0.889	0.597
$\bar{y}$	9.150	10.531	9.710	6.325	13.620	9.353	6.868
$\bar{x}$	7.912	11.576	17.381	25.593	22.081	19.509	7.162
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County-Decade FE					Yes	Yes	Yes
Cluster	County	County	County	County	County	County	County

See notes to Table 3.

Table 5: Homicide rate on Antenna Structure Density

	Homicides/100,000 Population				
	Sample: 1990s				
	Main CSA counties		All CSA counties		
	(1)	(2)	(3)	(4)	(5)
	Dependent Variable: A. Homicide[b] Rate				
Antenna[a]	-0.200**	-0.067***	-0.156**	-0.150***	-0.154**
	(0.083)	(0.022)	(0.068)	(0.058)	(0.063)
R^2	0.914	0.972	0.890	0.911	0.920
$\bar{y}$	14.976	14.976	10.433	10.433	10.433
	B. Employment[b] Rate				
Antenna	0.010	-0.054***	-0.009	-0.005	-0.005
	(0.030)	(0.008)	(0.015)	(0.015)	(0.016)
R^2	0.962	0.992	0.962	0.977	0.980
$\bar{y}$	61.552	61.552	61.619	61.619	61.619
	C. OD[c] Rate				
Antenna	-0.011	0.030***	0.023	0.018	0.019
	(0.027)	(0.008)	(0.028)	(0.024)	(0.026)
R^2	0.865	0.943	0.804	0.838	0.858
$\bar{y}$	7.384	7.384	5.897	5.897	5.897
$\bar{x}$	23.739	23.739	20.592	20.592	20.592
N	1,790	1,790	11,490	11,490	11,490
CSA-specific:					
Quadratic trend		Yes		Yes	
Year FE					Yes

All regressions include year and county fixed effects and are population weighted. Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
[a] – Sum of antenna structure shares/1000 square miles; antenna structures 200ft or taller within 20 miles of the county centroid; county area is the land area.
[b] Source: BLS. `https://www.bls.gov/lau/#cntyaa`.
[c] Source: NCHS.

Table 6: Homicides on Antennas – by Circumstance

	Homicide by Circumstance/100,000 Population				
	Sample: CSA Counties covered by Special Homicide Reports (SHR) Years: 1990s				
	Main CSA counties		All CSA counties		
	(1)	(2)	(3)	(4)	(5)
	A. Total Homicides (from Vital Statistics (NCHS))				
Antenna[a]	-0.063	-0.070***	-0.057	-0.082**	-0.082**
	(0.056)	(0.021)	(0.037)	(0.033)	(0.033)
R^2	0.922	0.973	0.909	0.930	0.930
$\bar{y}$	14.31	14.31	10.50	10.50	10.50
	B. Narcotics-Gang (from SHR)[b]				
Antenna	-0.016	-0.035***	-0.023	-0.031**	-0.031**
	(0.021)	(0.010)	(0.015)	(0.013)	(0.013)
R^2	0.755	0.920	0.749	0.819	0.819
$\bar{y}$	1.77	1.77	1.14	1.14	1.14
	C. Argument (from SHR)				
Antenna	-0.030	-0.015*	-0.042**	-0.042***	-0.042***
	(0.021)	(0.008)	(0.017)	(0.016)	(0.016)
R^2	0.828	0.925	0.795	0.832	0.832
$\bar{y}$	3.62	3.62	2.56	2.56	2.56
	D. Theft (from SHR)				
Antenna	-0.030*	-0.020***	-0.023*	-0.025**	-0.025**
	(0.017)	(0.003)	(0.013)	(0.010)	(0.010)
R^2	0.760	0.897	0.728	0.772	0.772
$\bar{y}$	1.49	1.49	0.98	0.98	0.98
	E. Miscellaneous (from SHR)				
Antenna	-0.003	-0.009	-0.006	-0.007	-0.007
	(0.007)	(0.007)	(0.005)	(0.006)	(0.006)
R^2	0.590	0.749	0.591	0.662	0.662
$\bar{y}$	2.67	2.67	2.03	2.03	2.03
	F. Undetermined or No SHR report (Panel A minus Panels B-E)[c]				
Antenna	0.016	0.010	0.038	0.023	0.023
	(0.071)	(0.026)	(0.054)	(0.047)	(0.047)
R^2	0.856	0.925	0.800	0.832	0.832
$\bar{y}$	4.75	4.75	3.80	3.80	3.80
$\bar{x}$	28.93	28.93	21.50	21.50	21.50
N	1,508	1,508	7,330	7,330	7,330
CSA-specific:					
Quadratic trend		Yes		Yes	
Year FE					Yes

See separate page for notes.

Table 7: Homicides by Victim Relationship to Offender

	Homicide by Relationship to Offender/10M Population				
	Sample: Special Homicide Reports, 1990s				
	Main CSA counties		All CSA counties		
	(1)	(2)	(3)	(4)	(5)
	A. Stranger[b]				
Antenna[a]	-0.428	-2.846**	-1.644	-2.227**	-2.227**
	(1.584)	(1.216)	(1.069)	(0.909)	(0.999)
R^2	0.684	0.802	0.700	0.744	0.807
$\bar{y}$	229.58	229.58	150.46	150.46	150.46
	B. Friends and Acquaintances				
Antenna	1.679	-1.665**	-2.373	-2.881*	-2.879
	(2.190)	(0.708)	(1.887)	(1.537)	(1.752)
R^2	0.793	0.904	0.758	0.810	0.847
$\bar{y}$	374.89	374.89	274.28	274.28	274.28
	C. Family				
Antenna	-0.154	-0.722*	-0.531	-0.680**	-0.681**
	(0.479)	(0.400)	(0.336)	(0.291)	(0.320)
R^2	0.606	0.738	0.493	0.533	0.609
$\bar{y}$	157.56	157.56	135.20	135.20	135.20
	D. Undetermined				
Antenna	-25.748	-1.697	-14.370	-12.766	-13.045
	(17.499)	(1.935)	(12.162)	(8.309)	(9.296)
R^2	0.871	0.958	0.864	0.895	0.907
$\bar{y}$	587.84	587.84	368.26	368.26	368.26
$\bar{x}$	28.93	28.93	21.50	21.50	21.50
N	1,508	1,508	7,330	7,330	7,330
CSA-specific:					
Quadratic trend		Yes		Yes	
Year FE					Yes

See separate page for notes.

Table 8: Homicides by Family Relations

	Within Family Homicide/10M Population				
	Sample: Special Homicide Reports, 1990s				
	Main CSA counties		All CSA counties		
	(1)	(2)	(3)	(4)	(5)
	A. Husband[b]				
Antenna[a]	0.183	0.131	0.037	0.040	0.018
	(0.159)	(0.113)	(0.098)	(0.052)	(0.059)[†]
R^2	0.419	0.584	0.266	0.310	0.418
$\bar{y}$	14.41	14.41	11.86	11.86	11.86
	B. Wife				
Antenna	0.195*	0.260	0.052	0.007	-0.027
	(0.113)	(0.248)	(0.097)	(0.099)	(0.105)[†]
R^2	0.345	0.524	0.293	0.328	0.420
$\bar{y}$	33.97	33.97	30.29	30.29	30.29
	C. Boyfriend				
Antenna	0.026	0.064	-0.069	-0.108	-0.123
	(0.069)	(0.083)	(0.061)	(0.071)	(0.084)
R^2	0.378	0.535	0.269	0.319	0.440
$\bar{y}$	12.10	12.10	9.65	9.65	9.65
	D. Girlfriend				
Antenna	-0.092	-0.310***	-0.152*	-0.181**	-0.179**
	(0.125)	(0.104)	(0.089)	(0.077)	(0.085)
R^2	0.302	0.472	0.266	0.300	0.413
$\bar{y}$	24.93	24.93	21.85	21.85	21.85
	E. Natal Family				
Antenna	-0.425**	-0.875***	-0.319**	-0.254*	-0.245
	(0.197)	(0.146)	(0.159)	(0.151)	(0.167)
R^2	0.325	0.489	0.271	0.308	0.425
$\bar{y}$	46.13	46.13	40.02	40.02	40.02
	F. Other Family				
Antenna	-0.040	0.007	-0.081	-0.185	-0.126
	(0.124)	(0.174)	(0.091)	(0.129)	(0.137)
R^2	0.364	0.529	0.280	0.318	0.421
$\bar{y}$	26.03	26.03	21.53	21.53	21.53
$\bar{x}$	28.93	28.93	21.50	21.50	21.50
N	1,508	1,508	7,330	7,330	7,330
CSA-specific:					
Quadratic trend		Yes		Yes	
Year FE					Yes

See separate page for notes.

Notes to Tables 6-8.

The sample is restricted to counties for which a homicide was reported on in the Special Homicide Reports (SHR). Franklin county, OH, home to Columbus, OH, was excluded because the number of homicides reported in the SHR were double those reported in the NCHS's Vital Statistics. This exclusion does not affect the results.

The population denominator is the county population.

The SHR does not disaggregate by borough the homicides in New York City. All city homicides are "given" to Manhattan, an allocation we keep (thus the main CSA county sample includes the whole of New York City). To accommodate this assignment, for the antenna density structure measure we use the population weighted mean for the five boroughs. Excluding New York City does not change the qualitative results.

All regressions include county and year fixed effects and are population weighted. Robust standard errors clustered at the county level in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

† – standard errors clustered at the CSA rather than the county level (in the latter case, standard errors would not compute).

[a] – Sum of antenna structure shares/1000 square miles; antenna structures 200ft or taller within 20 miles of the county centroid; county area is the land area.

[b] – For detailed breakdowns of categories, see Appendix Tables A1 and A2.

[c] – Number of homicides without a determined circumstance, either because there was not an SHR report or the SHR report left circumstance "undetermined."

Source: Supplementary Homicide Reports. `https://doi.org/10.3886/E100699V5`

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A1 Appendix Tables

Table A1: Homicide Circumstance – Contiguous US, 1976-2016

Description	Incidents	Victims	percent
Narcotics-Gang	56,675	60,074	8.3
[Violation of] narcotic drug laws	25,446	27,339	3.8
Juvenile gang killings	22,635	23,609	3.3
Brawl due to influence of narcotics	4,532	4,799	0.7
Gangland killings	4,062	4,327	0.6
Argument	205,966	212,360	29.3
Other arguments	191,686	197,635	27.2
Argument over money or property	14,280	14,725	2.0
Theft	63,912	67,160	9.3
Robbery	56,127	58,890	8.1
Burglary	5,901	6,283	0.9
Larceny	1,175	1,252	0.2
Motor vehicle theft	709	735	0.1
Miscellaneous	183,620	197,923	27.3
Other non-felony type homicide	86,352	92,432	12.7
Other – not specified	13,333	17,284	2.4
Felon killed by police	15,550	15,698	2.2
Brawl due to influence of alcohol	14,987	15,381	2.1
All suspected felony type	12,402	13,105	1.8
Felon killed by private citizen	11,685	11,900	1.6
Lovers triangle	10,141	10,812	1.5
Arson	2,903	4,547	0.6
Rape	4,051	4,158	0.6
All other manslaughter by negligence	2,977	3,144	0.4
Other negligent handling of gun	2,312	2,316	0.3
Other sex offense	1,395	1,441	0.2
Child killed by babysitter	1,235	1,243	0.2
Gambling	1,016	1,061	0.1
Institutional killings	1,018	1,035	0.1
Children playing with gun	868	868	0.1
Prostitution and commercialized vice	575	599	0.1
Sniper attack	470	547	0.1
Victim shot in hunting accident	250	252	0.0
Gun-cleaning death – other than self	90	90	0.0
Abortion	10	10	0.0
Undetermined	179,933	188,348	25.9
Total	690,106	725,865	100.0

Frequencies are for the first victim.
Source: Kaplan, Jacob. Uniform Crime Reporting (UCR) Program Data: Supplementary Homicide Reports, 1976-2016. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2018-06-19. `https://doi.org/10.3886/E100699V5`

Table A2: Homicide Relationship – Contiguous US, 1976-2016

Description	Incidents	Victims	Percent
Stranger	108,317	115,809	16.0
Friends and Acquaintances	209,416	218,645	30.1
Friend	24,704	25,439	3.5
Acquaintance	143,481	149,397	20.6
Employee	387	439	0.1
Employer	514	575	0.1
Homosexual Relationship	1,606	1,626	0.2
Neighbor	7,312	7,824	1.1
Other Known to Victim	31,412	33,345	4.6
Wife	28,519	29,806	4.1
Wife	25,374	26,595	3.7
Common-Law Wife	3,145	3,211	0.4
Husband	14,152	14,226	2.0
Husband	11,479	11,547	1.6
Common-Law Husband	2,673	2,679	0.4
Boyfriend	8,588	8,615	1.2
Girlfriend	18,115	18,724	2.6
Natal Family	32,657	36,898	5.1
Son	9,747	10,975	1.5
Daughter	7,043	8,202	1.1
Brother	6,085	6,346	0.9
Father	4,771	5,140	0.7
Mother	4,274	4,780	0.7
Sister	1,237	1,455	0.2
Other Family	20,906	22,620	3
In-Law	4,289	4,685	0.6
Ex Wife	2,125	2,311	0.3
Stepfather	1,618	1,675	0.2
Stepson	1,319	1,418	0.2
Ex Husband	853	859	0.1
Stepdaughter	719	852	0.1
Stepmother	219	258	0.0
Other	9,764	10,562	1.5
Undetermined	248,936	260,522	35.9
Total	690,106	725,865	100.0

Frequencies are for the first victim and the first offender.
Source: Kaplan, Jacob. Uniform Crime Reporting (UCR) Program Data: Supplementary Homicide Reports, 1976-2016. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2018-06-19. https://doi.org/10.3886/E100699V5

A2 Appendix – Antenna Structures – FCC

The Antenna Structure Registration data were downloaded from:
`http://wireless.fcc.gov/uls/index.htm?job=transaction&page=weekly`

We match the latitude and longitude information to the nearest county centroid reflecting county boundaries as of 2000, obtained from:
`http://www.census.gov/tiger/tms/gazetteer/county2k.txt`

A3 Appendix – Mortality data – National Center for Health Statistics (NCHS)

The NCHS data corresponds to the data available on death certificates and are thus the most complete data on deaths in the US.

An advantage of the NCHS data is that the five New York City boroughs are reported separately with respect to occurrence (deaths can also be by residence).

The NCHS data include place of occurrence and place of residence. We restrict the data to US residents and for location we use place of occurrence.

The NCHS data only contain information from some 400 counties in 1989 and therefore we exclude that year.

For year 1972, only half of deaths were included and therefore we multiply deaths in that year by two.

A4 Appendix – Population data – Census

We used the Census' county level population estimates, available at

`https://www.census.gov/programs-surveys/popest/data/data-sets.All.html`

A5 Appendix – Homicide data – Special Homicide Reports

The data `shr_1976_2016.csv` version V5[2018-06-19] can be downloaded from:
`https://www.openicpsr.org/openicpsr/project/100699/version/V5/view`

For a description of the variables in the SHR, please see:
`https://ucr.fbi.gov/nibrs/addendum-for-submitting-cargo-theft-data/shr` Participation in the SHR is voluntary and not all agencies report.

An agency is identified by its ORI(ginating agency) number.

Each row is an incident, and the ORI, year, month and incident number identifies each incident. Each incident can have several homicide victims and several offenders.

A couple of adjustments were made.

First, when the National Center for Health Statistics reported zero homicides for a county and the SHR did not have any reported homicides, we assumed a zero homicide rate for that county in the SHR data as well, on the assumption that NCHS would typically have the "correct" number and that zero homicides is plausible reason for the corresponding SHR data to be missing.

Second, homicide data for New York City are not disaggregated to the county level. Therefore, for this data set, we exclude New York City.

Third, there were a few duplicate observations (roughly 350), looking over them, some of them were "adjustments", for those we used the adjusted record.

A5.1 Circumstance

The circumstances are coded for all offenders, for detailed categories see Table A1.

In the cases of multiple offenders (4 percent of incidents and 9 percent of victims), in more than 98 percent of the cases with more than one offender, only one circumstance was given (i.e., the same circumstance was stated for all offenders).

In cases with multiple circumstances, the priority was as follows:

Narcotics-Gang > Theft > Argument > Miscellaneous >Undetermined

A5.2 Relation

For detailed categories see Table A2. This information is only available for victim 1. If a husband kills his wife and n other people, we count all n homicides as being of this type although only victim 1 was killed by her husband.

In case of multiple victims, we apply the same relationship for the first victim to all victims. While somewhat arbitrary, these additional victims may be viewed as collateral damage swept up by the primary conflict.

There is information on up to 11 offenders. For instance, for a woman murdered by her husband and a friend, the first relationship variable might be codes as husband and the second as friend. We created two indicator variables, one which indicates all homicides in which a relationship, say friend, was mentioned, and one which assigns only one relationship to each incident. In practise, these two measures yielded almost identical results and therefore we went with the measure that assigns a unique relationship so as to avoid double counting.

To assign a unique relationship, relationships need to be prioritized. In the above example, the victim was a wife and a friend. We prioritize "closeness" resulting in the following order of priority:

Husband, wife >Family-Natal > Boyfriend, girlfriend > Family-Other > Friends and acquaintances > Strangers > Undetermined.