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Kluin, M.H.A.; Blokland, A.A.J.; Huisman, W.; Peeters, M.P.

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# Longitudinal patterns of regulatory violations in chemical corporations

**Marieke H. A. Kluin**[1] · **Arjan A. J. Blokland**[1,2] · **Wim Huisman**[3] · **Marlijn P. Peeters**[1]

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## Abstract

Unlike criminal career research into the criminal behavior of natural persons, longitudinal research into regulatory violations by corporations is still scant. The few available longitudinal studies mostly suffer from either a small sample size or a short follow-up period, limiting the generalizability of their findings. The present study uses longitudinal data on rule violating behavior of 567 chemical corporations having to comply with the EU Seveso Directive in the Netherlands, derived from yearly inspections (N = 5.975) of the relevant safety, occupational health and environmental agencies between 2007 and 2021. The study aims to gain insight in the patterning of regulatory violations by Dutch Seveso corporations, and the extent to which these patterns are associated with sector and corporate characteristics. The results show that regulatory violation is common among Dutch Seveso corporations. A small minority of chronically violating corporations however, is responsible for a disproportional share of all observed regulatory violations. Using group-based trajectory modelling (GBTM) we distinguish several longitudinal patterns of regulatory violations in our data. Available sector and corporation characteristics are found to be only weakly associated with the patterns of regulatory violations identified.

**Keywords** Life-course criminology · White-collar crime · Seveso corporations · Regulatory enforcement · Group-Based Trajectory Modelling

## Introduction

Research into the criminal careers of individual offenders has yielded important insights into the origins of delinquency, the course of criminal careers, and the development of criminal behavior over the life-course (Sullivan & Piquero, 2016). Criminal career research, for instance, has consistently shown a small portion of individuals to be responsible for the lion's share of offending (Piquero et al., 2003), but also that criminal careers which are at some point much alike, may diverge as

Extended author information available on the last page of the article

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individuals age, whereas for others initially distinct criminal careers may at some point show substantial convergence (Jennings & Reingle, 2012). Such empirical insights are used to explain criminal development, to identify appropriate targets and moments for interventions, and to predict the impact of such interventions on future lawbreaking (MacLeod et al., 2012; Visher, 2016). While life-course criminological research initially focused on 'street' offenses, the life-course perspective is increasingly being applied to particular crimes and offender populations, including white collar criminals (e.g. Van Onna et al., 2014). As for criminology in general, this has spurred theoretical development in these subfields of inquiry (e.g. Piquero & Benson, 2004).

Only recently, a number of authors have begun to also explore the potential merits of the life-course perspective for explaining crimes committed by corporations (Blokland et al., 2021; Hunter, 2021; Meester et al., 2024; Simpson, 2019; Simpson et al., 2025; Wu et al., 2024). A life-course approach to corporate crime is less strange than it might seem at first sight. Firstly, an anthropomorphic approach to corporations is common in organizational sciences (Miller & Friesen, 1984). Organizational scientists view corporations as deciding actors that have particular traits and show certain behaviors (Huisman, 2016). Organizational criminology also implies corporate actors as it defines corporate crime as lawbreaking by corporations (Braithwaite, 1985). Furthermore, in many countries, being legal entities, corporations can be held liable for violations of different laws and regulations, just like individuals. Secondly, business administration has developed business life cycle models, describing the life-course of corporations distinguishing phases within them, each with their own their challenges and risks (Greiner, 1972; Levie & Lichtenstein, 2010; Phelps et al., 2007, Quinn & Cameron, 1983). Like in individuals, different phases in the corporate life cycle may be differentially linked to the risk of breaking laws (Hunter, 2021; Simpson, 2019). Thirdly, longitudinal research into corporate crime is not entirely without precedent. In fact, the founding father of the criminological study of white-collar crime already studied historical records of lawbreaking by America's largest corporations (Sutherland, 1939, 1949, 1983). The present paucity of longitudinal research in organizational criminology is mainly due to availability – or rather the unavailability – of longitudinal data (Schell-Busey, 2022; Simpson, 2019). As a result, much extant organizational criminological research is of a qualitative nature and limited to case studies (Verhage, 2009). Though qualitative case studies may be longitudinal, they typically are retrospective, entailing the risk that the corporation's past is interpreted from the context of the scandal that is typically the cause of the case study in the first place (Shover & Hochstetler, 2002). For yielding new insights, prospective longitudinal research therefore is preferred. Finally, as with individuals, various factors can influence the onset, course and desistance of a corporation's criminal career. In humans, these factors are both internal and external, and are typically related to demarcated phases of life, such as hormonal levels, delinquent friends, and ties to work and marriage (Blokland & Nieuwbeerta, 2010). While these specific factors do not apply to corporations, there may be relevant internal and external factors at the corporate level that similarly influence the likelihood of regulatory violation and provoke distinct patterns in rule breaking behavior over the corporate life cycle (Huisman, 2016; Kluin, 2014). These

factors might, for example, be important changes in the management or the financial position of the corporation (Simpson, 2013; Wang & Holtfreter, 2012), but could also refer to macro-economic factors (Kennedy, 2019).

Since at present longitudinal research into criminal careers of corporations is still scarce, there is currently little insight into the patterns of corporate offending of corporations, and the factors related to these patterns. This study will therefore examine the longitudinal patterns in both the extent and nature of regulatory violations of a large number of Dutch chemical corporations, as well as the corporate characteristics related to these patterns. For the purpose of this study we will focus on a specific group of corporations that handles, transports or stores hazardous substances above a certain amount. To minimize associated risks, these corporations must comply with the European Union Seveso-III Directive (Directive 2012/18/EU). As the risks related to the violation of this Directive for local residents, employees and the environment are high, these chemical, or Seveso corporations have the special interest of responsible inspection agencies. Consequently, most corporations are inspected annually, bi-annually, or every three years, the results of which are registered in a digital repository. In turn, this repository allows for constructing an extensive longitudinal data set pertaining to these corporations, their inspections, and their regulatory violations. Using this data set, the current study aims to answer the question whether corporations with different patterns of regulatory violations can be distinguished, and if so, to what extent these patterns are associated with certain industry and corporate characteristics. Describing variation in corporate offending and the characteristics associated with it, is an important first step in the developmentally informed explanations of corporate crime.

In the remainder of the introduction, we first briefly discuss some of the promises and pitfalls of a life-course perspective on corporate crime. We then summarize results of earlier longitudinal research on regulatory violations by corporations, and the related industry and corporate characteristics. After highlighting the added value of the current study, the available data on Seveso corporations in the Netherlands and the research methods are explained. We then provide results on the prevalence and patterns of regulatory violations and related corporate characteristics. The conclusion paragraph elaborates on future directions of longitudinal research in organizational criminology and the value of a life-course perspective on corporate offending for enforcement practice.

## A longitudinal (life-course) approach to corporate crime

Applied to corporate crime, a life-course approach would first be cognizant of the temporal dimension of corporations' offending. Is the number of violations going up or down during a certain period, and are these violations becoming increasingly diverse or severe? Meticulously describing longitudinal patterns of corporate offending may yield important insights in common pathways and point to promising explanations of corporate rule breaking. Linking offending dimensions over time, may also provide ground for predicting future corporate behavior; to what extent, for instance, does a history of frequent yet minor violations predict gross disregard

of the rules in the future? Next, much like natural persons, corporations go through different life phases (inception or initial growth, expansion or rapid growth, maturity, revival, and decline), each posing their own managerial and financial challenges. Again, like natural persons, corporations may have difficulty facing these challenges, which, in turn, may give rise to different types of rule violations. For instance, in expanding businesses, management focus typically is on the company's short-term performance (Smith et al., 1985), inducing more risky managerial decisions (Phelps et al., 2007) that may put expanding companies particularly at risk of violations. In businesses facing rapid decline, managerial tactics will be orientated toward preserving the company's core, issuing budget cuts to preserve the company's current resources (Cameron & Zammuto, 1983). Financial stress in the declining phase is also found to elicit excess levels of risk taking causing companies to increasingly violate employee safety rules, though this appears to change when businesses are facing bankruptcy (Filer & Golbe, 2003). A life-course criminology of corporate crime may seek to identify the challenges that characterize different phases in the corporate life-cycle, and the ways in which these challenges promote rule breaking behavior. Finally, corporations may experience exogenous events and transitions, such as periods of economic downturn, exigent regulatory requirements, or hostile takeovers, that may impact some or all dimensions of corporate offending. The extent of this impact may furthermore depend on the corporations' history of rule violations as the corporation's current phase in the corporate life-cycle.

The theoretical and practical importance of considering the time dimension is illustrated by Fig. 1, which represents five hypothetical criminal career paths A to E observed over some period *t*. Summed over *t*, A accumulates less offenses than E. Paths B, C and D however would yield the same number of crimes, despite marked differences in the developmental trend of their offending. First, taking time into account thus allows for a more fine-grained description of offending. Second, considering the development of offending over time guides theoretical thinking

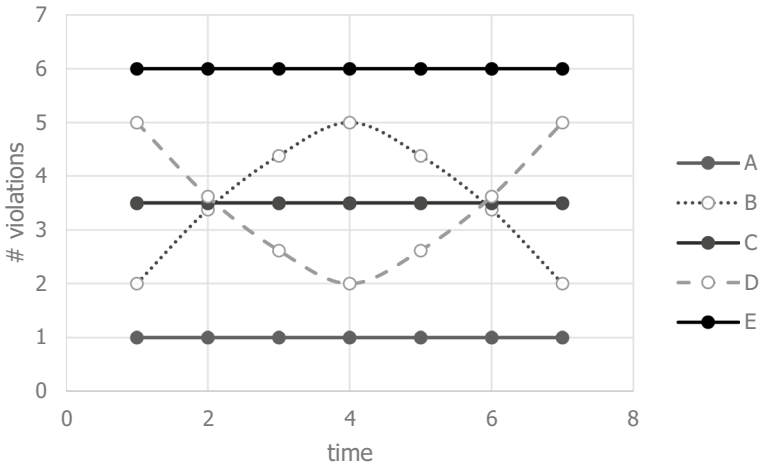



**Fig. 1** Five hypothetical violation trajectories

when seeking explanations for the criminal behavior observed. Whereas differences between path A, C, and E might intuitively be best explained by between-unit differences on some stable characteristic, explanations of path B and D would likely involve the influence of dynamic variables changing over time. Considering time also has important practical ramifications. Based on the overall number of offenses across *t*, those on career path E would constitute obvious targets for selective attention and intervention. Taking time into account however, would also highlight group D as worthy of immediate attention, whereas group B would seem less of a current concern. This reasoning holds regardless of whether the criminal career paths considered are those of individual offenders, or represent corporate offending.

While both theoretically and practically promising, a life-course criminology of corporate crime does face some conceptual challenges that are unique to corporate actors. First, for individuals calendar age is an intuitive organizing principle, as many biological, cognitive, and social variables are associated to calendar age in a more or less linear fashion. For corporations however, mere calendar age may be far less informative regarding the challenges faced by corporations (Blokland et al., 2021). Corporations might for instance go through a period of sudden growth after a prolonged period of stability. Furthermore, whereas biological ageing in individuals proceeds in an irrevocable fashion, basic parameters of corporations, like size and organizational structure, may evolve much more erratically. Second, at present there is more consensus on the different developmental stages individuals go through than there is agreement on what could be considered the stages of corporate development, what challenges corporations might face during these stages, and how corporations meet these challenges would impact the likelihood and nature of their offending (Beaudry et al., 2020; Habib and Hasan, 2019). Even the most definitive stages of human development, birth and death, do not translate readily to corporations, as in case of mergers and take-overs it might be difficult to pinpoint where a corporation as an independent unit begins and ceases to exist. Finally, a longitudinal approach to corporate crime only has merit to the extent that longitudinal data on both corporate offending and the hypothesized drivers of that offending are available, or could be made available (Simpson, 2019). Corporate behavior may be governed by many laws and regulations, and, as a result, by as many inspectorates. Fragmentation of information presents a challenge specific to a life-course criminology of corporations.

## Prior research on longitudinal patterns in corporate crime

Despite early pleas for longitudinal research into corporate crime (Clinard & Yeager, 1980), thus far only a very limited number of truly longitudinal studies – with a follow-up period of at least five years – have been conducted. Findings of those studies vary both with regard to the prevalence of corporate offending in the population, the frequency of that offending, and the disproportionate contribution of a small minority of frequently offending corporations to the totality of offenses for the sample under scrutiny. Edwin Sutherland (1949, 1983) was the first to call attention to violations committed by corporations. Sutherland analyzed the sanctions

of courts and administrative commissions against the 70 largest, non-financial corporations in the United States over the life-span of these corporations, which was about 45 years (1983, p. 13). He found that 68 corporations (97.1%) were recidivists, accumulating 980 sanctions in total, averaging 14 violations each. Simpson (1986) studied violations of antitrust legislation by American corporations. The long follow-up – 55 years, from 1927 through 1981 – resulted in a final sample of only 52 corporations. These 52 corporations were responsible for a total of 477 violations, averaging 9 violations each. Of the 384 Fortune-500 corporations studied by Dalton and Kesner (1988), 25 percent (N = 95) was convicted between 1980 and 1984. The study of Baucus and Near (1991) also focused on Fortune-500 corporations. They found that of the 88 corporations convicted between 1963 and 1981, 30 percent (N = 26) was convicted for regulatory violations more than once during this period. Hill and colleagues (1992) studied the distribution of 343 environmental violations and 6.233 violations of the labor inspection in 174 Fortune 1000-corporations between 1985–1988. Their research showed that a small group of 11 corporations was responsible for more than 10 environmental violations each. Alexander and Cohen (1996) examined the offending of 101 public manufacturing corporations between 1972 and 1994. The average number of violations of these corporations was 1.19. The largest category of corporate crime involved fraud followed by environmental crime, and antitrust violations. Harte (2011) studied Fortune-500 corporations that had been convicted more than once for white collar crime between 1990–2007. The 50 convicted corporations were convicted 126 times in total; an average of 2.52 times each. In the largest longitudinal study thus far, Kedia and colleagues (2017) studied violations of safety, environmental and antitrust legislation by 12,587 US corporations between 1994–2011. More than 36 percent of the corporations violated the rules at least once. The most persistently offending corporations, were found in violation in at least 8 of the 10 years studied. Finally, Simpson, Layana and Galvin (2025) analyze the development of financial and environmental offending in 3,385 large companies between 1996 and 2013. They find that 15.4 percent of the companies violates the rules at least once. Based on the frequency of offending, they distinguish three groups, two of which show stable low levels of offending during the entire observation period, and a third group that shows a steep decrease from initially high levels of offending.

To date, to our knowledge the only non-American studies are those by Alalehto (2010) and Meester et al. (2024). Alalehto (2010) studied corporate violations for the 70 highest ranked corporations in the Swedish business market over a ten-year period based on court decisions (criminal, civil and administrative law) concerning various offenses. More than 85 percent of the corporations were found to have violated the legal rules at least once. A small percentage of "frequently offending" corporations were responsible for a disproportionate share of the total number of violations – about 7 percent of the corporations committed more than 30 violations each. Meester et al. (2024) studied corporate offending in Dutch inland shipping. Of the 4.036 companies included in this study, 66.2 percent ($N = 2{,}673$) were found to violate the rules at least once during the 5-year follow up, with an average of 3.52 offenses per company. A minority of 9.6 percent of these companies was responsible for almost half (49.4%, $N = 7{,}014$) of all violations. These authors distinguish four

offending trajectories in their sample: a constant low group, an increasing group, a decreasing group, and a constant high group.

Lastly, a number of studies made use of data sources other than official registered convictions, detected violations or suspicions by enforcement authorities. Block and colleagues (2006) and Mishina and colleagues (2010) studied media covered violations of US corporations in the period 1990–1999. They found more than 400 unique violations committed by just under 200 unique corporations. The only longitudinal self-report study is that of Gibbs and Simpson (2009) on polluting behavior of 67 American corporations between 1995 and 2000. These corporations reported two violations per year on average.

In sum, previous longitudinal studies on corporate crime typically found offending to be common, especially when not only criminal but also administrative violations are taken into account, but the distribution of offending rates between corporations to be uneven. However, by aggregating the violations across the entirety of the follow-up, most of these studies did not differentiate in the patterning of these violations over time. Those studies that were able to distinguish different trajectories in corporate offending find important differences in the (de-)acceleration of offending between trajectories, suggesting that corporate offending trajectories, like those of individuals, might be open to dynamic outside influences (Simpson et al. 2025).

## Explaining corporate crime

Criminologists tend to explain corporate offending from variables that can be considered either stable or dynamic, depending on the rate at which these variables typically change in relation to the observation period under scrutiny. On the industry-level, the type of industrial activity would be an example of a stable variable, whereas the level of competition can be considered more dynamic. On the corporate level variables like corporate size, organizational structure and corporate culture, though liable to long-term change, can typically be considered as stable, whereas corporate financial performance would be considered dynamic in most longitudinal studies.

### Criminogenic industries

Industry characteristics might be related to corporate offending. Which industries are at a higher risk however, is not agreed upon. In their study of Fortune 500 corporations Staw and Szwajkowski (1975) found that violations in competition law could be related to the economic business environment (see also Palmer, 1972; Asch & Seneca, 1976). Clinard and Yeager (1980) concluded that corporate crime is particularly prevalent in the oil, automotive and pharmaceutical industry. Simpson (1986) concluded that the chemical, oil, refining, steel and automotive industry are considerably more criminogenic than the aircraft industry. Using the same selection of corporations, but looking at the risk of recidivism, Simpson and Koper (1992) found that the oil and automobile industry pose an overall higher risk of recidivism,

while in all sectors the economic condition of the industry seemed to influence the degree of recidivism. The study by Baucus and Near (1991) also showed differences between branches with corporations in the food, wood, oil refining and transport industry tending to be more deviant than others. Harte (2011) found most convictions for corporations in the transport, communication, electricity, gas and sanitary services industry. In Sweden, Alalehto (2010) found the largest number of convictions among producing corporations, followed by corporations within the energy supply sector. At present, the existing body of research makes it plausible that some industries are more criminogenic than others, but it is uncertain what kind of industries these are.

### Corporate characteristics

Summarizing the current state of knowledge, a recent multilevel meta-analysis by Pusch and Holtfreter (2021) found several organizational characteristics to emerge as predictors of corporate crime. Company size significantly predicted offending in both bivariate and multivariate analyses, while financial strain was significant only in multivariate models. The mean effect size for the ethical subculture variable was significant when bivariate statistics were examined, suggesting that the internal climate of a company may also help explain offending in some situations (Pusch & Holtfreter, 2021).

Prior research finds both stable and dynamic corporate characteristics to be associated with corporate offending, though the exact nature of those relationships is still unclear (Simpson, 2013). Within the limits of the data available for the current study, we explore the associations between stable industry and corporate characteristics and corporate offending pathways. Explanations of corporate crime that focus on stable characteristics are in many ways the anti-thesis of developmental explanations. To the extent that offending pathways are predicted by stable corporate characteristics, this would therefore question the need for a life-course approach.

## Current research

The current research adds to a small but growing literature taking a life-course perspective on corporate crime, and is among the first to empirically assess the development of corporate offending over an extended period of time. The present research does not only describe between-corporate differences in the level of offending – as did most prior studies -, but also examines within-corporate developments in offending over time. As such, the current study lays important ground work for future research attempting to explain corporate criminal careers. More specifically, the current research combines a national wide sample of 567 Dutch Seveso corporations with an observation period of fifteen years. As such, it provides important information about the prevalence and patterning of violations by these corporations. The research relates to corporations in the Dutch Seveso industry, which need to adhere to specific guidelines due to the presence of dangerous chemicals. Previous

qualitative research at fifteen Dutch Seveso corporations found that different patterns of regulatory violation could be identified based on corporations' history of regulatory violations (Kluin, 2014). To reconstruct longitudinal patterns of regulatory violations by Seveso corporations, the current research uses a national register of inspection data, the Gemeenschappelijke Inspectie Ruimte (GIR). The analysis in this article address the following questions:

What is the extent of regulatory violations among Dutch Seveso corporations in the period 2007–2021?
Can longitudinal patterns in regulatory violations be distinguished in the 2007–2021 period?
To what extent are violations and pathways therein related to industry and corporation characteristics?

## Seveso industry and regulation in The Netherlands

Currently, about 400 chemical corporations are active in the Netherlands (Brzoplus, 2023a). These corporations vary from complex chemical industrial corporations to relatively simple storage corporations for dangerous substances. These corporations need to adhere to strict safety standards, as put down in the EU Seveso-III Directive. The goal of this directive is the prevention and control of severe accidents involving dangerous substances. Based on the amount and type of substances within a facility, it is determined to which obligations a corporation needs to adhere (Brzoplus, 2020). Compliance to the directive is inspected annually, biennial or every three years – depending on the corporate risk level – using on-site inspections. Inspectors from multiple inspectorates carry out the inspection together in a joint inspection approach. Inspection teams work together in the preparation, execution and completion of the inspection according to a nationally uniform inspection methodology. At system-level, inspectors check whether corporations work safely and have insight into the state of their risks, processes and installations. In addition, random physical inspections are carried out to check whether the documentation of the corporation corresponds to the actual situation (Kluin, 2014). Inspections are announced in advance, but there may also be unannounced inspections during the year.

## Data and methods

### Sample

The results of the joint inspections are registered in a national register of inspection data Gemeenschappelijke Inspectie Ruimte (GIR). The GIR constitutes an online joint working space for the various Dutch Seveso inspection authorities that are involved and has existed since 2006. GIR is mainly used as a tool for planning, preparing and constructing inspections and follow-ups such as sanctions. As of January

2022, the GIR database contained information on 5,975 inspections of 567 unique Seveso corporations, which is an average of 10.5 inspections per corporation.

### Inspection data in GIR

Table 1 provides descriptive statistics pertaining to inspections, inspection topics, and registered violations regarding the 567 unique corporations in the current sample. Of the corporations registered in the GIR, 40 (7.10 percent) were inspected only once in the period 2007–2021, while the most inspected corporation had 47 inspections in that period. Differences in the total number of inspections can be due to a number of reasons. First, not all corporations have existed or have been subjected to a licensing requirement for the entirety of the follow-up. Second, administrative agreements may have been made as to the frequency of inspections. Finally, some corporations may have received more attention from the inspection agencies than others. As violations can only be detected during an inspection, the amount of available data varies per corporation. Moreover, inspections may differ in the number and nature of the topics inspected. The 567 unique corporations in our sample that were inspected at least once, were inspected in total 5,975 times. This amounts to an average of 10.54 inspections per corporation. During the data collection, 175 different inspection topics (and therefore 175 different possible violations) were distinguished. For the current analyses, these have been reduced to twelve umbrella categories, including the eight elements of the safety management system (Brzoplus, 2023b). The inspections covered a total of 27,228 inspection topics, with the average corporation being inspected for

**Table 1** Descriptive statistics of inspections, inspection topics, and violations, 2007–2021

| | Number | Range | Average | SD |
|---|---|---|---|---|
| Number of unique corporations | 567 | | | |
| Number of inspections | 5,975 | | | |
| Average number of inspections per corporation | | 1–47 | 10.54 | 6.42 |
| Number of inspection topics | 27,228 | | | |
| Average number of unique inspection topics per inspection | | 1–10 | 4.56 | 2.06 |
| Average number of inspection topics per corporation | | 1–175 | 48.02 | 28.35 |
| Average number of unique inspection topics per corporation | | 1–14 | 10.02 | 2.07 |
| Number of violations | 11,079 | | | |
| Percentage of corporations with at least one violation | | 0–100 | 93.80 | |
| Average number of violations per corporation | | 0–129 | 19.54 | 18.22 |
| Average number of violations per corporation with at least one violation | | 1–129 | 20.83 | 18.08 |
| Percentage of inspections with at least one violation | | 0–100 | 56.35 | |
| Average number of violations per inspection | | 0–37 | 1.85 | 2.75 |
| Average number of violations per inspection with at least one violation | | 1–37 | 3.29 | 2.95 |

10 (out of 12) unique topics, and an average of 4.56 unique inspection topics per inspection. The 5,975 inspections of 567 corporations yielded a total of 11,079 violations, with 93.80 percent of the corporations being registered for a violation at least once between 2007–2021. The amount of rule violations is determined based on all violations included in the inspection reports. These are violations of regulations that monitor external safety, working conditions and the environment. Topics of potential violations include the storage of hazardous substances, the reporting of incidents, the fire-extinguishing system or the emergency plan. One or more violations were found in 56.35 percent of all inspections, with a maximum of 37 and an average of 3.29 violations. The average corporation in our sample had 19.54 registered violations during the follow up – 20.83 if only corporations with at least one violation are considered –, an average of almost 2 violations per inspection.

### Industry and corporation characteristics in GIR

The GIR does not contain data on industry and corporate characteristics found in the literature discussed above, such as corporate size or financial performance. However, three Seveso-specific industry and corporation characteristics can be distinguished from the GIR. First, based on the Major Accident Reporting System created by the EU (MARS), corporations can be classified according to the nature of their activities. These MARS categories are also mentioned in the GIR database and are a proxy for the type of industry. Table 2 shows that wholesale and distribution comprises 21.87 percent ($N=124$) of the corporations mentioned in the GIR, followed by general chemistry (21.16 percent: $N=120$) and handling and transportation (18.34 percent: $N=104$). Second, depending on the permitted quantities of hazardous substances, two categories of Seveso corporations are differentiated: lower-tier and upper-tier establishments. The obligations of lower-tier establishments are the preparation of a major-accident prevention policy (MAPP) and the maintenance of a safety management system. In this study, 233 Seveso corporations fall under this category. Corporations that exceed the high threshold value are referred to as upper-tier establishments. They must have a full safety report in addition to the aforementioned obligations demonstrating that the prevention and control of the major accident hazards are in order (Directive 2012/18/EU). An upper-tier establishment need to ensure that this safety report reflects current safety arrangements, this report is available within the establishment and is required to have an internal emergency plan and an updated inventory of all the existing dangerous substances. In the current study 334 Seveso corporations fall under this high threshold. Third, a corporation can be qualified as a 'Domino-plant' when it is located in the immediate vicinity of another lower- or upper-tier establishment. Proximity to other Seveso corporations increases the possible consequences of an accident or undesirable event at the neighboring corporation, creating a domino-effect. A designation as a domino plant brings extra obligations for the corporation. 131 corporations were classified as a domino plant. The characteristics of the sample are shown in Table 2.

**Table 2** Characteristics of the 567 corporations in the sample

| | *N* | % |
|---|---|---|
| Number of unique corporations | 567 | 100 |
| **MARS category** | | |
| Wholesale and retail storage and distribution | 124 | 21.87 |
| General Chemicals manufacture | 120 | 21.16 |
| Handling and transportation centers | 104 | 18.34 |
| Other[1] | 70 | 12.35 |
| Pesticides, pharmaceuticals and other fine chemicals | 30 | 5.29 |
| Waste treatment and disposal | 26 | 4,0.9 |
| Power supply and distribution | 25 | 4.41 |
| Metal refining and processing | 21 | 3.70 |
| Plastics and rubber manufacture | 18 | 3.17 |
| Petrochemical, refining and processing | 15 | 2.65 |
| Uncoded | 14 | 2.47 |
| **Obligation** | | |
| Upper-tier establishment | 334 | 58.91 |
| Lower-tier establishment | 233 | 41.09 |
| **Domino plant** | | |
| no | 434 | 76.54 |
| yes | 131 | 23.10 |
| unknown | 2 | 0.35 |

[1]The 'Other' category refers to MARS-categories: 'Other', 'Food and drink', 'Timber and furniture', 'AGRIculture', 'Ceramics', 'Medical research and education', 'Electronics and electrical engineering', 'General engineering manufacturing and assembly'

## Group based trajectory modelling

In this study, group-based trajectory modeling (GBTM) (Nagin, 2005) is used to determine to what extent different patterns of rule violation by corporations can be distinguished from 2007 to 2021. Using longitudinal data on the annual frequency of rule violations by the Seveso corporations in the sample, GBTM can help distinguish between clusters of corporations that show similar developments in the frequency of rule violation over time. Unlike hierarchical or growth curve models, GBTM does not assume an average developmental pattern of which individual corporations can deviate to a greater or lesser extent. Instead, development over time is shown in a limited number of distinct patterns which differ from one another based on the start, frequency and duration of the rule violating behavior. It is assumed these patterns are related to various business and contextual factors. For this study, we estimated GBTMs from 1 to 9 groups. Based on the values of the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC) and other available fit measures, such as the average probability of being assigned to a certain group considering the pattern of rule violation, a choice was made for the most suitable model (Nagin, 2005). GBTM

is robust for missing data (Nagin & Land, 1993). This is relevant for the current study, since rule violation can only be detected when an inspection has actually occurred. Here we estimate rule violation trajectories on a yearly basis. In principle, all corporations that are subjected to the Seveso guidelines are inspected yearly, bi-yearly, or every three years. When a corporation was inspected more than once in a single year, the number of inspection subjects and the number of violations were summed up. It is also possible, that corporations seize to exist or come into existence during the observation period, or begin to fall or no longer fall under the Seveso guidelines because they have (in)sufficient hazardous substances at hand. This also causes the number of inspections per corporation to differ. Of all corporations in our sample 7.10 percent was inspected once, 12.30 percent was inspected twice during the study's follow-up period; 75 percent was inspected five times or more. Group membership is determined within GBTM on the data available for that specific corporation. This means that the corporations for which only violation data was available from one inspection were allocated to trajectory groups based on the level of their offending observed during this inspection rather than the shape of their offending career.

## Results

### Distribution of regulatory violations among Dutch Seveso corporations

Results show that the corporations in our sample are found to violate the rules approximately 19 times over our 15-year observation period (RQ1). The 11,079 registered violations are not equally distributed among all 567 corporations in our data. As shown in the left bar of Fig. 2, 6.17 percent of corporations inspected at least once during the follow-up of the study has no registered violations (see also Table 2). Another 18.34 percent has between 1 and 5 registered violations. For a minority of 11.11 percent of all corporations in the current sample, more than 40 violations were noted. The right bar of Fig. 2 shows the percentage of all violations registered during the follow-up period these corporations are responsible for. Whereas those corporations that have between one and three registered violations account for 2.98 percent of all registrations. The 11.11 percent of corporations with each more than 40 violations, account for 33.60 percent of all violations registered for the corporations in our sample during the follow up period. This is despite the fact that these corporations account for only 19.50 percent of the total number of inspections (middle column). The disproportionate share of frequently violating corporations in the total number of violations therefore, does not seem to be wholly the result of disproportionate attention of the inspection agencies for these particular corporations. As in earlier studies, we thus find that a small percentage of corporations is responsible for a disproportionate share of all registered violations.

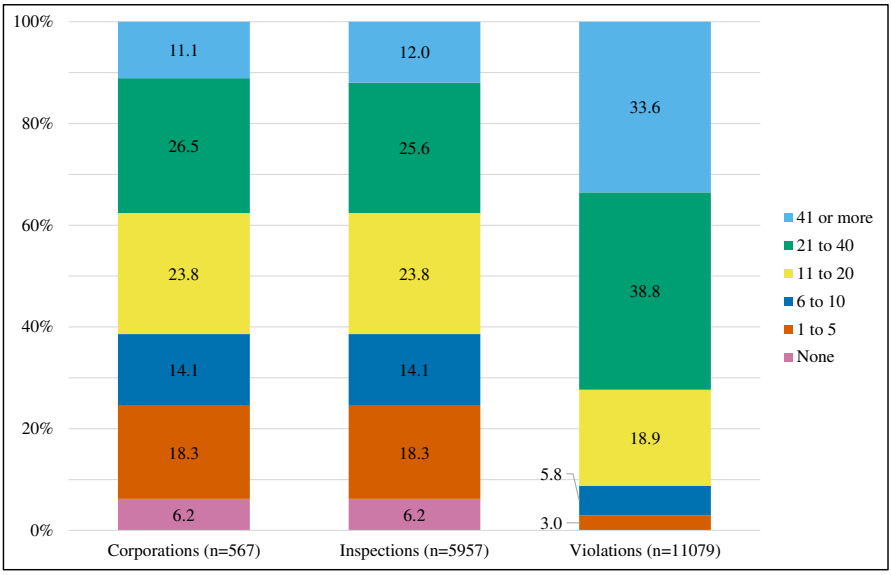



**Fig. 2** Distribution of corporations, inspections, and violations across corporations, years 2007–2021

## Corporations, inspections and violations per MARS-category

To gain a first insight into the extent overall levels of violations are associated with industry and corporation characteristics (RQ3), Fig. 3 provides the percentages of corporations, inspections and violations per MARS-category (horizontal bars, bottom axis). The MARS-categories are ordered based on prevalence in our sample, with the least prevalent category at the top, and the most prevalent category at the bottom. For reasons of privacy, we only report on those MARS-categories for which there were more than 15 unique corporations in our data, otherwise they are included in the category 'Other'. Figure 3 shows that corporations involved in wholesale and distribution comprise 21.87 percent of the sample, are responsible for 22.71 percent of the total number of inspections, and account for 27.01 percent of all violations registered for the corporations in our sample from 2007 until 2021. Corporations involved in wholesale and distribution are thus slightly overrepresented in terms of registered violations, corporations in handling and transport are underrepresented in the distribution of violations.

Figure 3 also depicts the average number of registered violations per inspection topic per MARS-category (white bars). Corporations, that are 'uncoded', or that fall under waste treatment and disposal, metal refining and processing, and corporations involved in whole sale, retail and distribution, are found to violate more often given the total number of inspection topics for corporations in these categories. Corporations in power supply and distribution show fewest violations per inspection.

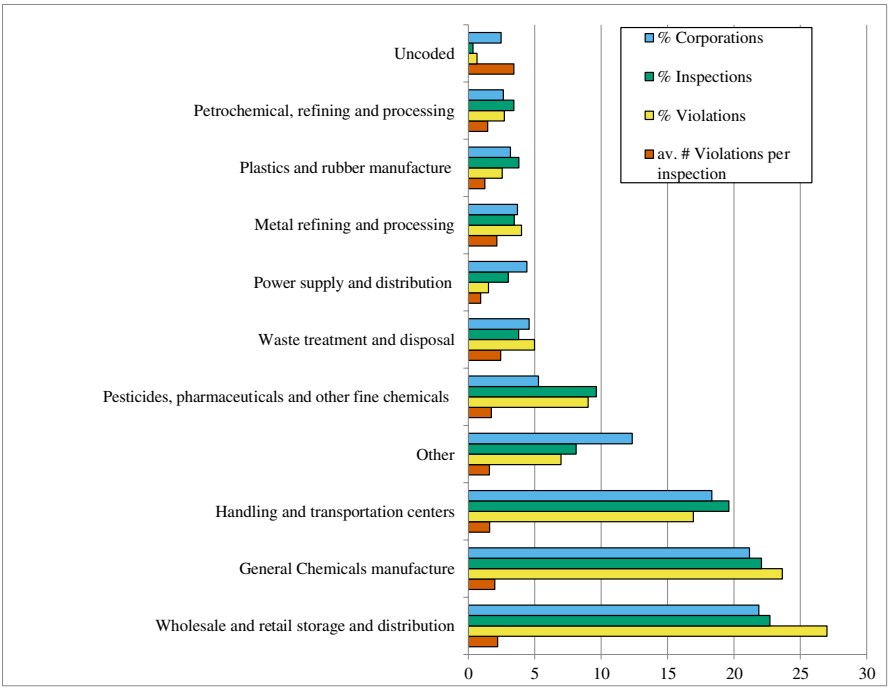
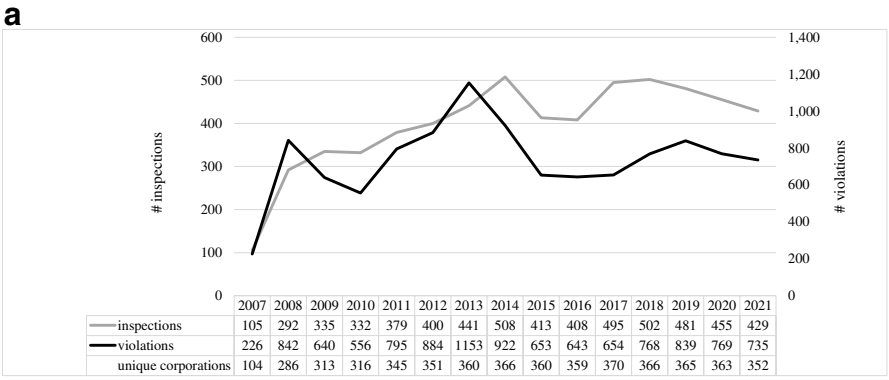



**Fig. 3** Percentages of corporations, inspections, and violations per MARS-category

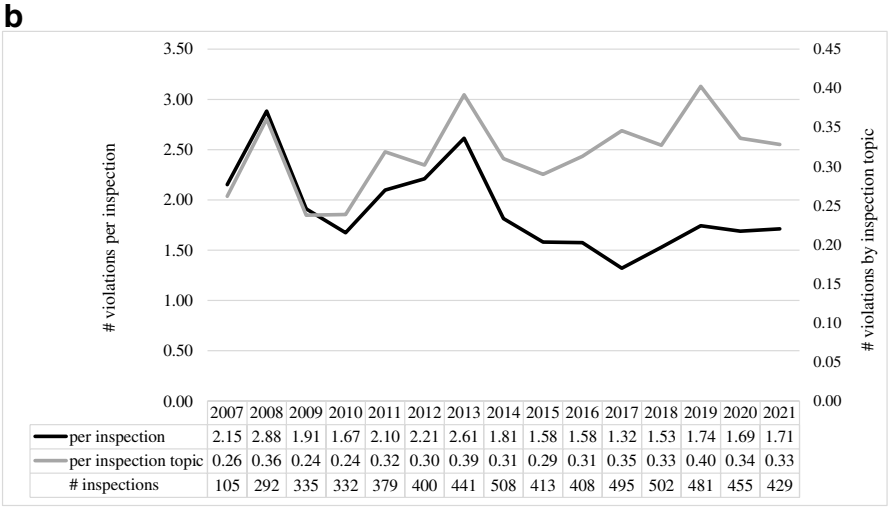
## Overall trends in registered violations and inspections over time

Figure 4a depicts the 15-year trend in the number of inspections and the number of violations registered as a result of these inspections. The number of registered violations increases from 226 in 2007 to a peak of 1,153 in 2013, to decrease to 753 in 2021. As to register a violation, there has to be an inspection. Figure 4a also depicts the 15-year trend in the number of inspections. The number of inspections increases across the follow-up period, suggesting that the increase in registered violations may for a large part result from an increasing number inspections. As shown in Fig. 4a, the rise and decline in the number of inspections, in turn, is partly due to the fluctuating number of unique corporations falling under the Seveso-regime each year that are candidates to inspection.

In Fig. 4b the average number of violations per inspection is plotted against the calendar year. The average number of violations peaks in 2008 and again in 2013, yet the overall trend is slightly declining. To control for possible time-trends in the number of topics inspected during inspections, Fig. 4b also depicts the average number of violations per inspection topic per year. Again, despite peaks in 2008 and 2013, and a drop in 2017, the long-term trend in the average number of violations per year, controlled for the number of inspections, is




| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| inspections | 105 | 292 | 335 | 332 | 379 | 400 | 441 | 508 | 413 | 408 | 495 | 502 | 481 | 455 | 429 |
| violations | 226 | 842 | 640 | 556 | 795 | 884 | 1153 | 922 | 653 | 643 | 654 | 768 | 839 | 769 | 735 |
| unique corporations | 104 | 286 | 313 | 316 | 345 | 351 | 360 | 366 | 360 | 359 | 370 | 366 | 365 | 363 | 352 |




| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| per inspection | 2.15 | 2.88 | 1.91 | 1.67 | 2.10 | 2.21 | 2.61 | 1.81 | 1.58 | 1.58 | 1.32 | 1.53 | 1.74 | 1.69 | 1.71 |
| per inspection topic | 0.26 | 0.36 | 0.24 | 0.24 | 0.32 | 0.30 | 0.39 | 0.31 | 0.29 | 0.31 | 0.35 | 0.33 | 0.40 | 0.34 | 0.33 |
| # inspections | 105 | 292 | 335 | 332 | 379 | 400 | 441 | 508 | 413 | 408 | 495 | 502 | 481 | 455 | 429 |

**Fig. 4** **a**. Total number of registered violations and of inspections by year, 2007–2021. **b**. Average number of violations per inspection and per inspection topic by year, 2007–2021

near horizontal. As of 2010, the average number of violations per inspection topic however increases more steeply than the number of violations per inspection and remains elevated after that. This suggests that although the number of inspections has remained more or less similar, the number of inspection topics per inspection has decreased.

### Longitudinal patterns in regulatory violations

In the next step of our analysis we turn to time trends in registered violations on the corporate level, that is, we ask whether distinct patterns in the number of registered violations can be distinguished over the follow-up period of our data (RQ2). We use GBTM for this purpose. As GBTM can handle missing data due to right censoring,

we only exclude the data of 2006 from our analysis – as we have data on only one inspection during this year –, but include the available inspection data for 2021.

To account for potential differences in inspection efforts, when corporations were inspected more than once during a given year, we averaged the number of violations across these inspections. We estimated GBTM models for 1 up to 9 groups. Corporations are assigned to the trajectory that best fits their observed pattern of regulatory violations. Figure 5 depicts the results from the 7-group model – the model that produced the best fit to our data given the indices provided. These trajectories are best seen as latent strata in the longitudinal data. As individual corporations may not be inspected every year, or start to be subject to or cease to be subject to Seveso regulations during a year, corporations may not be inspected during every year between 2007 and 2022.

The patterns found represent different dimensions of rule violating behavior. Therefore, the results of the GBTM can be analyzed in different ways. Concentrating on the estimated number of yearly violations (frequency), Fig. 5 shows that with three trajectories the yearly number of violations for corporations never exceeds two (groups 1, 3 and 4). These corporations with a low (maximum) frequency of violation, make up 59.61 percent of the sample, while being responsible for 36.76 percent of all registered violations from 2007 until 2021. For group 5 (15.34 percent of the sample; 25.43 percent of the registered violations) the average frequency of violations ranges from 2 to 5. Group 7 (5.82 percent of the sample; 12.72 percent of the violations) has an estimated number of yearly violations between 3 and 9. Compared to the corporation with a low frequency in violations (groups 1, 3 and 4), corporations in group 5 and 7 can be considered as high frequent violators. However, dividing corporations based on average frequency of offending is a rather rough measure. Groups 2 and 6 are difficult to categorize solely in terms of average frequency of offending, as their trajectories cross other trajectories, and are thereby confusing the

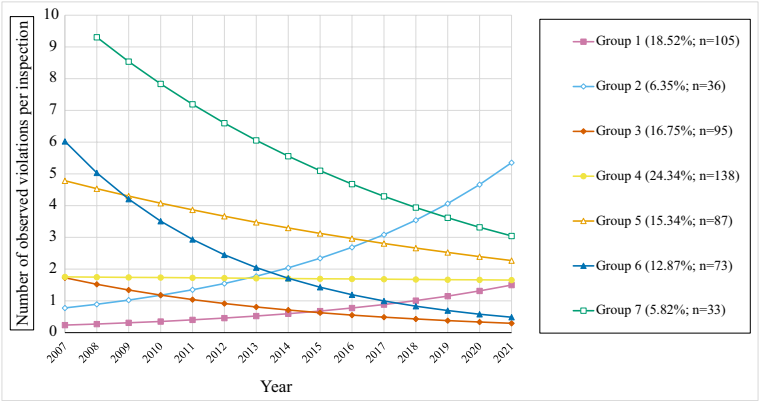



**Fig. 5** Patterns of regulatory violations, 2007–2021

grouping in low and high frequency offenders. Furthermore, besides showing a relatively high level of violations, the trajectories of groups 5 and 7, show converging longitudinal trends.

A second way of looking at Fig. 5, is therefore to focus on the longitudinal trend in the yearly number of regulatory violations. Whereas groups 3, 5, 6 and 7 show a downward trend in the number of yearly violations, groups 1 and 2 show an increasing number of violations over time. Group 4 shows a stable trend of about 1.7 violations per inspection per year. Trajectories with a decreasing trend represent 50.8 percent of the sample. These include the groups of corporations with the highest levels of violations. Groups 1 and 2 show and increasing trend and represent 24.9 percent of the sample, while being responsible for a growing percentage of the total number of violations per year. From a regulatory perspective, corporations in group 7 shows positive development, dropping from being among the most frequently violating corporations to violating levels comparable to the group with the lowest violation frequency. Group 2 on the contrary, starts at the second lowest level in 2007 but ends as the most frequently offending group in 2021.

### Inspections, inspection topics and regulatory violations per trajectory group

As the long-term trends for the entire sample (Fig. 4a and 4b), the patterns in Fig. 5 result from a combination of the number of actual inspections and the number of violations found during those inspections. To determine to what extent the patterns are influenced by possible differences in the number of actual inspections, Table 3 shows the number of inspections, inspection subjects and violations per group (compare Table 1). Anova (for continuous variables) and $Chi^2$ tests (for dichotomous variables) show that the corporations in different trajectories differ significantly from each other on all the characteristics mentioned in Table 3. Post-hoc tests (Tukey HSD) show that corporations in groups 1 are inspected less frequently and inspected on fewer subjects than corporations allocated to trajectories 4 and 6. Also, the (average) number of violations is lower for corporations in groups 1 compared to all other groups, and lower in group 2, 3 and 4 compared to groups 5, 6 and 7. The findings show that the latter is not entirely due to the smaller number of inspections. If the total number of inspections per corporation is also taken into account, the average number of violations for corporations in groups 1 remains significantly lower than that from corporations in all the other groups but group 3. Figure 5 visually displays the percentage of corporations, inspections and violations comparable to Fig. 1, but this time per GBTM group. Figure 6 shows that, regardless of the differences found in Table 3, the sizes of the trajectory groups largely correspond to the respective percentages of the total number of inspections conducted in each group. This suggests that differences in the frequency and development of rule violation as shown in Fig. 5 and the right-hand bar in Fig. 6, are mainly the result of differences in rule violating behavior, rather than differences in the extent to which these corporations are subjected to inspections.

**Table 3** Inspections, inspection topics, and violations 2007–2021 per trajectory group

| | Trajectory group | | | | | | | Total sample |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Number of unique corporations | 105 | 36 | 95 | 138 | 87 | 73 | 33 | 567 |
| Number of inspections | 927 | 407 | 1007 | 1586 | 878 | 888 | 282 | 5975 |
| Average number of inspection per corporation | 8,83 | 11,31 | 10,60 | 11,49 | 10,09 | 12,16 | 8,55 | 10,54 |
| Number of inspection topics | 4012 | 1963 | 4462 | 6985 | 4295 | 4063 | 1448 | 27228 |
| Average number of unique inspection topics per inspection | 4,33 | 4,82 | 4,43 | 4,40 | 4,89 | 4,58 | 5,13 | 4,56 |
| Average number of inspection topics per corporation | 38,21 | 54,53 | 46,97 | 50,62 | 49,37 | 55,66 | 43,88 | 48,02 |
| Average number of unique inspection topics per corporation | 9,12 | 10,61 | 9,82 | 10,02 | 10,40 | 10,86 | 9,97 | 10,02 |
| Number of violations | 659 | 1130 | 756 | 2658 | 2817 | 1650 | 1409 | 11079 |
| Percentage of corporations with at least one violation | 0,78 | 1,00 | 0,87 | 1,00 | 1,00 | 1,00 | 1,00 | 0,94 |
| Average number of violations per corporation | 6,28 | 31,39 | 9,11 | 19,26 | 32,38 | 22,60 | 42,70 | 19,54 |
| Average number of violations per corporation for corporations with at least one violation | 8,04 | 31,39 | 9,11 | 19,26 | 32,38 | 22,60 | 42,70 | 20,83 |
| Percentage of inspections with at least one violation | 0,15 | 0,56 | 0,56 | 0,75 | 0,83 | 0,96 | 0,94 | 0,64 |
| Average number of violations per inspection | 0,71 | 2,78 | 0,75 | 1,68 | 3,21 | 1,86 | 5,00 | 1,85 |
| Average number of violations per inspection for inspections with at least one violation | 1,87 | 4,25 | 2,24 | 2,64 | 4,29 | 3,18 | 6,21 | 3,29 |

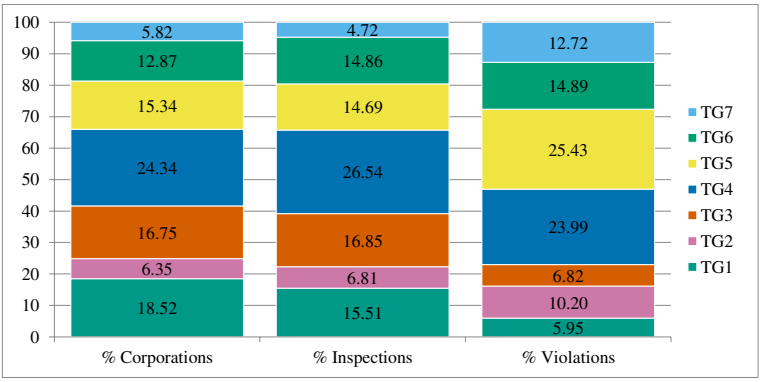



**Fig. 6** Distribution of corporations, inspections, and violations across trajectory groups, years 2007–2021

To further illustrate the added value of examining the longitudinal patterning of corporate violations, Table 4 shows a crosstabulation of the categorization of corporations based on the overall number of violations during the observation window – as in Fig. 2 -, and the categorization based on the distinguished trajectory groups – as in Fig. 5 and 6. As expected, those corporations with no more than five violations are overrepresented in the low-level declining trajectory groups 1 and 3, and underrepresented in the high-level trajectory groups 5 and 7. Likewise, those corporations with over 40 violations are overrepresented in the high-level trajectory groups 5 and 7 and under represented in the low-level declining groups. However, what remains unnoted when characterizing corporations by the total number of violations, but does become clear when analyzing the longitudinal pattern of their offending is that over three quarters of the corporations with over 40 violations show a declining trend in the number of violations during the observation window, whereas 13.24 percent is showing a clear increase during that same period.

**Table 4** Percentage of all corporations with a certain total number of violations per trajectory group

| | Trajectory group | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | TG1 | TG2 | TG3 | TG4 | TG5 | TG6 | TG7 | Total |
| *# of violations* | | | | | | | | |
| 0 violations | 65.71 | 0.00 | 34.29 | 0.00 | 0.00 | 0.00 | 0.00 | 100 |
| 1–5 violations | 36.54 | 0.00 | 29.81 | 24.04 | 5.77 | 3.85 | 0.00 | 100 |
| 6–10 violations | 20.00 | 3.75 | 26.25 | 18.75 | 7.50 | 16.25 | 7.50 | 100 |
| 11–20 violations | 19.26 | 5.93 | 20.00 | 26.67 | 14.81 | 9.63 | 3.70 | 100 |
| 21–40 violations | 1.38 | 11.03 | 2.76 | 37.93 | 17.24 | 26.21 | 3.45 | 100 |
| 40 + violations | 0.00 | 13.24 | 0.00 | 10.29 | 44.12 | 7.35 | 25.00 | 100 |
| Total sample | 18.52 | 6.35 | 16.75 | 24.34 | 15.34 | 12.87 | 5.82 | 100 |

### Industry and corporation characteristics per trajectory group

Finally, based on the data available, we explore the association of corporate characteristics and trajectory group membership (RQ3). Table 5 describes the different corporation characteristics listed in Table 1 (MARS categorization, lower/upper-tier, and domino plant) per GBTM group. The table shows both the absolute numbers (left side of the table) and row percentages (right side of the table). Of the total of 567 corporations in the current sample, 105 are classified as group 1 which comprises 18.5 percent of the total sample. The general impression distillated from Table 5 is that almost all characteristics are represented in each of the groups. This means that membership of a certain group is not "typical" for a certain category of corporations (or vice versa: that a certain corporation characteristic is not "typical" for corporations in a certain group). Test results per corporation characteristic confirm this idea: the corporations in the different groups do not differ significantly from each other in terms of MARS category, or current obligation ($F(6,560) = 0.848$, $p = 0.534$; $F(6,560) = 1.397$, $p = 0.214$). Domino plants are less frequent among group 1 than among groups 5 and 6, less often among group 3 than among groups 6 ($F(6,558) = 4.44$, $p = 0.000$; Tukey HSD). While domino plants may engage in more complex industrial processes, and hence be more liable for rule violations, this would not readily explain their overrepresentation in decreasing trajectories.

## Discussion and conclusion

Longitudinal research into rule violations by corporations is scarce. Most of the available research pertains to either a small sample or a short observation period, which limits the possibilities for generalization of the results. More importantly, most prior studies report only aggregate outcomes for the entire follow-up period, and fail to examine the temporal development of corporate offending. The current study used a large, nationally representative sample of Dutch Seveso corporations to determine longitudinal patterns of rule violations over an observation period of fifteen years. Corporate offending by Dutch Seveso corporations are by no means a rare phenomenon: nine out of ten corporations violated the Seveso directives at least once between 2007 and 2021. On average, 19 offenses per corporation were detected by the collaborating inspection agencies during that period. A comparably high prevalence was also found in earlier research (e.g. Alalehto, 2010; Meester et al., 2024; Sutherland, 1949, 1983). When interpretating these figures it is important to realize that the seriousness of the violation was not taken into account in the current research; a standardized proxy for the seriousness of violations has been added to the GIR only recently. Information about the danger arising from the rule violations is therefore missing in the current analyses. As a result, an employee having a cup of coffee in a room where people are working with dangerous substances adds to a corporation's rule violations the same way as does a gross neglect of the safety regulations leading to a devastating fire. In their ambition of applying responsive regulation (Ayres & Braithwaite, 1992), Dutch regulatory agencies do not only

**Table 5** Industry and corporate characteristics per trajectory group

| | Trajectory group | | | | | | | Total sample | Trajectory group | | | | | | | Total sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Number of unique corporations | 105 | 36 | 95 | 138 | 87 | 73 | 33 | 567 | 18,52 | 6,35 | 16,75 | 24,34 | 15,34 | 12,87 | 5,82 | 100 |
| MARS category | | | | | | | | | | | | | | | | |
| Wholesale and retail storage and distribution | 8 | 5 | 17 | 38 | 27 | 20 | 9 | 124 | 6,45 | 4,03 | 13,71 | 30,65 | 21,77 | 16,13 | 7,26 | 100 |
| General Chemicals manufacture | 24 | 11 | 15 | 28 | 18 | 17 | 7 | 120 | 20,00 | 9,17 | 12,50 | 23,33 | 15,00 | 14,17 | 5,83 | 100 |
| Handling and transportation centers | 21 | 7 | 27 | 25 | 11 | 9 | 4 | 104 | 20,19 | 6,73 | 25,96 | 24,04 | 10,58 | 8,65 | 3,85 | 100 |
| Other[1] | 18 | 2 | 11 | 17 | 12 | 7 | 3 | 70 | 25,71 | 2,86 | 15,71 | 24,29 | 17,14 | 10,00 | 4,29 | 100 |

**Table 5** (continued)

| | Trajectory group | | | | | | | Total sample | Trajectory group | | | | | | | Total sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Pesticides, pharmaceuticals and other fine chemicals | 4 | 3 | 6 | 6 | 4 | 4 | 3 | 30 | 13,33 | 10,00 | 20,00 | 20,00 | 13,33 | 13,33 | 10,00 | 100 |
| Waste treatment and disposal | 3 | 1 | 1 | 7 | 5 | 5 | 4 | 26 | 11,54 | 3,85 | 3,85 | 26,92 | 19,23 | 19,23 | 15,38 | 100 |
| Power supply and distribution | 9 | 0 | 9 | 1 | 0 | 5 | 1 | 25 | 36,00 | 0,00 | 36,00 | 4,00 | 0,00 | 20,00 | 4,00 | 100 |
| Metal refining and processing | 2 | 4 | 3 | 6 | 5 | 1 | 0 | 21 | 9,52 | 19,05 | 14,29 | 28,57 | 23,81 | 4,76 | 0,00 | 100 |

**Table 5** (continued)

| | Trajectory group | | | | | | | Total sample | Trajectory group | | | | | | | Total sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Plastics and rubber manufacture | 9 | 1 | 2 | 1 | 3 | 2 | 0 | 18 | 50,00 | 5,56 | 11,11 | 5,56 | 16,67 | 11,11 | 0,00 | 100 |
| Petrochemical, refining and processing | 2 | 2 | 4 | 5 | 1 | 1 | 0 | 15 | 13,33 | 13,33 | 26,67 | 33,33 | 6,67 | 6,67 | 0,00 | 100 |
| Uncoded | 5 | 0 | 0 | 4 | 1 | 2 | 2 | 14 | 35,71 | 0,00 | 0,00 | 28,57 | 7,14 | 14,29 | 14,29 | 100 |
| Obligation | | | | | | | | | | | | | | | | |
| Upper-tier establishment | 50 | 24 | 56 | 89 | 51 | 46 | 18 | 334 | 14,97 | 7,19 | 16,77 | 26,65 | 15,27 | 13,77 | 5,39 | 100 |
| Lower-tier establishment | 55 | 12 | 39 | 49 | 36 | 27 | 15 | 233 | 23,61 | 5,15 | 16,74 | 21,03 | 15,45 | 11,59 | 6,44 | 100 |
| Domino plant | | | | | | | | | | | | | | | | |
| no | 90 | 22 | 81 | 95 | 58 | 47 | 20 | 413 | 21,79 | 5,33 | 19,61 | 23,00 | 14,04 | 11,38 | 4,84 | 100 |
| yes | 15 | 13 | 14 | 42 | 29 | 26 | 13 | 152 | 9,87 | 8,55 | 9,21 | 27,63 | 19,08 | 17,11 | 8,55 | 100 |
| unknown | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0,00 | 50,00 | 0,00 | 50,00 | 0,00 | 0,00 | 0,00 | 100 |

[1]The 'Other' category refers to MARS-categories: 'Other', 'Food and drink', 'Timber and furniture', 'AGRIculture', 'Ceramics', 'Medical research and education', 'Electronics and electrical engineering', 'General engineering manufacturing and assembly'

need to include frequency of offending, but also the safety risks and harms associated with violations into their monitoring and sanctioning decision-making (van de Bunt et al., 2007). The first important next step in the longitudinal investigation of corporate offending therefore, should involve adding information of the seriousness of the violations encountered.

Like in previous research (e.g. Hill et al., 1992; Kedia et al., 2017), we find a small group of corporations that are frequently found to be noncompliant, accumulating over 40 registered violations over a period of 15 years. Together, the frequently offending corporations in our study were responsible for a third of all registered violations during the observation period. Provided that their non-compliance is not limited to the least serious of violations, interventions successful in increasing the level of compliance in these corporations are likely to impact the safety situation in the Seveso industry as a whole. An important advantage of the available GIR data in this respect is that, in addition to the number of registered rule violations, the GIR contains information on the behavior of the inspection agencies involved. Hence it was possible to demonstrate that the high number of violations by the "frequently offending" corporations was not fully an artifact of an elevated inspection pressure on these corporations. In life-course criminological research into the criminal careers of natural persons, data on the enforcement behavior of relevant parties – for example the police, or the Public Prosecution Service – is generally lacking and data of registered offenses are used under the implicit assumption that everyone, always, has the same chance of being arrested, prosecuted or tried, given that they behave criminally. This while individual criminal careers also develop against the background of an enforcement landscape which is continuously subject to changes in, for example, investigation priorities or prosecution policy (see for example: Francis et al., 2015). The available GIR data enabled us to isolate the "behavior" of corporations from changes in the behavior of the enforcement authorities involved.

The GBTM analysis shows that, in addition to identifying a group of high-frequency rule violating corporations, the rule-violating behavior of some corporations shows a rising trend over time, while that of other corporations goes down. The reasons for the divergence of these trajectories are currently unknown. Given that membership in a certain group does not seem to be limited to corporations from one particular industry, these reasons will have to be distinguished at the level of the individual corporation. A second important next step in the longitudinal study of corporate offending therefore lies in the collection of additional longitudinal corporate data that can help to explain the patterns found. An important, but nevertheless hard to unequivocally operationalize (Dang et al., 2018), characteristic to be added is, for example, corporate size. When results would show a positive relationship between corporate size and the likelihood of rule violation, a rising trend in rule violation could be the result of the growth of the corporation and not so much due to over time changes in 'behavior' of the corporation.[1]

To explain differences in rule violation, previous theorizing on corporate crime suggested various typologies (Bardach & Kagan, 1982; Gunningham et al., 2003;

[1] Admittedly, this gets more complex if corporation size does not only influence rule violation, but also the'behavior' of corporations.

Haines, 1997; Hutter, 1997; Kagan & Scholz, 1984), attributing static straits and motivational postures to types of corporations. Such classifications are usually based on cross-sectional, qualitative research and typically refer to the underlying causes of compliance and non-compliance, for example, whether rule violation is due to negligence, intent or accidents (Hawkins, 1984; Hutter, 1997; Kagan & Scholz, 1984). Such typologies offer rather static classifications of corporations and their intentions to comply. They thus seem to suggest that a corporation belongs to a certain category rather indefinitely. Also, previous research on Dutch Seveso corporations (Kluin, 2014) suggested that corporations stay in the same category during the studied time frame (1999–2011). The long-term trajectories found in this study however, seem to contradict such a static classification of corporations. Corporations that violate the rules often at the beginning of the observation period, do not necessarily still do so at the end of the observation period. Ayres and Braithwaite (1992, p. 30–35) argue against classifying corporations into certain categories. They claim that corporations can, for example, both be an amoral calculator and an incompetent business, and that this can differ per time period. This is also in line with our finding that static characteristics were not associated with particular trajectory groups, with the caveat that we were only able to include three industry-specific corporate characteristics. In light of potential changes in corporations' motivations for non-compliance over time, and given that information on the corporations' motives for and potentially relevant corporate characteristics related to rule violation is absent in the GIR data – although certain proxies could perhaps be deduced from these data – we deliberately chose to stay away from allocating substantive labels on the distinct patterns of rule violations found at this point. Importantly, our findings indicate that regulatory enforcement needs to be responsive and be aware of differences between corporations and potential developments therein over time. While Dutch enforcement authorities aim to implement this strategy of responsive regulation, they often do not have the information required to do so (van de Bunt et al., 2007). Keeping track of corporations' violation histories over prolonged periods of time is a pivotal first step to allow enforcement to responsively respond to corporate violations.

It is important to realize that in the current research patterns of corporate offending are analyzed using calendar time. In life-course criminological research on individual perpetrators calendar time and developmental time run more or less synchronously: phases of life like adolescence and adulthood are usually defined on the basis of calendar years. Business life cycle models also distinguish different phases in the life of corporations (Lester et al., 2003). Other than life stages of individuals however, not only the length of these different life phases, but even the sequence of these phases may differ between corporations. An important future avenue for a life-course criminological approach of corporate crime will therefore have to consist of longitudinally operationalizing the different life phases of a corporation, in such that 'age' of the corporation acquires more meaning than the mere period of existence (Habib and Hasan, 2019). Relatedly, within life-course research of individual perpetrators, there is much attention to life-course events, such as finding work, getting married, and having children, which – when appropriately timed – can mitigate individuals' criminal behavior (Blokland & Nieuwbeerta, 2010). Within a life-course criminological approach

to corporate crime it is interesting to contemplate what would be the corporate equivalents of the events and transitions that might help explain the longitudinal patterning of rule violation by corporations (Blokland et al., 2021). Such events may be related to dynamic factors such as financial strains and radical changes in the gender composition of corporate boards (Huisman, 2016). Like with substantiating corporate age, future longitudinal research in corporate non-compliance depends heavily on the type of corporate information that is available to be linked to long-term non-compliance data.

The life-course criminological investigation into individual perpetrators has had an important influence on both criminological theory formation and criminal justice policy and practice. The potential of a life-course criminological perspective on corporate crime we consider correspondingly large. Especially now more and more longitudinal enforcement data are becoming available. Follow-up studies of this and other available datasets will have to show to what extent this potential can be realized.

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**Author contributions** All authors provided equal and original contributions. Marieke Kluin performed the final edit. All authors read and approved the final manuscript.

**Data availability** The corresponding author can be contacted with questions about the data and access to the data.

## Declarations

**Ethical approval** Not applicable.

**Informed consent** Not applicable.

**Statement regarding research involving human participants and/or animals.** Not applicable.

**Competing interests** Wim Huisman is Editor-in-Chief for Crime Law and Social Change. The other authors have no relevant financial or non-financial interests to disclose.

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## Authors and Affiliations

**Marieke H. A. Kluin[1] · Arjan A. J. Blokland[1,2] · Wim Huisman[3] · Marlijn P. Peeters[1]**

✉ Marieke H. A. Kluin
m.h.a.kluin@law.leidenuniv.nl

Arjan A. J. Blokland
ablokland@nscr.nl

Wim Huisman
w.huisman@vu.nl

Marlijn P. Peeters
m.p.peeters@law.leidenuniv.nl

[1] Leiden University, Steenschuur 25, 2311 ES Leiden, The Netherlands

[2] Netherlands Institute for the Study of Crime and Law Enforcement (NSCR), P.O. Box 71304, 1008 BH Amsterdam, the Netherlands

[3] Vrije Universiteit Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands