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Drivers and frictions of workplace accidents: an empirical investigation of cross-country European heterogeneity

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Drivers and frictions of workplace accidents: an empirical investigation of cross-country European heterogeneity

Abstract. This paper presents an empirical investigation on the determinants of workplace accidents across Europe and focuses on the extent to which production-system characteristics (employment sectoral risk, size of firms, temporary contracts), business cycle and socio-economic factors (GDP, level of investments, unemployment, education) and other territorial controls (crime index) might account for cross-country heterogeneity. We use Eurostat data, and our panel is composed of 27 European countries over the period 2010-2018. Implementing, different functional forms/estimation methodologies (pooled OLS, panel fixed and random effects models, system-GMM and semiparametric fixed effects model), we find robust evidence that productive-system structural characteristics, business cycle controls and the other territorial variables are effective in explaining European cross-country heterogeneity. Moreover, we find evidence of a nonlinear relationship between GDP and occupational accidents. Finally, in a policy implication perspective, our results provide evidence that forms of direct financial support to SMEs investments in OSH (as implemented in Italy with the so-called ISI initiative, launched by the National Institute for Insurance against Accidents at Work from 2010 onwards) can represent a successful policy tool potentially applicable to other European countries.

Keywords: occupational accidents, European productive-system, business cycle, European countries, system-GMM, semiparametric fixed effects model

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1. Introduction

Workplace safety is a relevant issue that has been increasingly attracting the attention of institutions, labour organizations, researchers, and policy makers (EC, 2002, 2007). In Europe, even though the number of occupational injuries shows a decreasing trend, cross-country differences in workplace accident rates show a heterogeneous dynamic mainly related to differences in definitions and measurement (Boone and van Ours, 2006). In Italy, from 2008 to 2019, the highest percentage of work accidents occurred in those sectors that are typically considered particularly at risk and that employ vulnerable workers (low-skilled, low-paid, low-educated), such as manufacturing industries, construction, trade, and transport activities. Even though, over the past few years, the total of accidents in Italy, like in the other European countries, has decreased (Hämäläinen *et al*., 2009), the work-related risks, however, have not been reduced in a uniform way leaving some categories of workers, companies and sectors overexposed to workplace risks (Cioni and Savioli, 2016). In Italy, for instance, Central-Northern provinces have a higher proportion of employment in industrial sectors (in comparison to the Southern regions) which pose a higher risk of work accidents/injuries. A large amount of literature has investigated the issue of occupational accidents and illnesses from different perspectives, and in relation to a combination of multifaceted determinants stemming from individual and workplace-related factors to socio-economic and institutional characteristics.

The frequency of workplace accidents has been extensively studied in the literature, and have been traditionally identified four main groups of factors affecting injuries (see Fabiano *et al*., 2004): i) individual factors related to workers characteristics (age, gender) and experience (Fotta and Bockosh, 2000; Jeong, 1999; Kletz, 1993), ii) job-related factors (Ferguson *et al*., 1985; Rasmussen, 1987; Vredenburgh, 2002), organization of work (Shannon *et al*., 1996) and environmental conditions (Fabiano *et al*., 2001), iii) technology used (Blank *et al*., 1996b; Sari *et al*., 2004; Asogwa, 1988; Laflamme and Cloutier, 1988), and iv) economic factors, such as general economic conditions, unemployment rate, labour and social insurance legislation, business cycles (Asfaw *et al.*, 2011; Davies *et al*., 2009; Brooker *et al*., 1997; Blank *et al*., 1996a). More recently, Cornelissen *et al*. (2017) have provided one of the most comprehensive overviews on the determinants in literature on occupational safety, identifying and clustering several possible determinants of occupational injuries in high-risk industries (i.e., construction, petro-chemistry, warehouses, and manufacturing). In their study, they categorized the identified factors into seven clusters: i) workplace characteristics and circumstances (i.e., company size, safety equipment, shifts, working hours, contract type, job level, workforce quantity and composition, unions, HR, ecc.), ii) climate and culture (i.e., organizational climate and culture, safety climate and culture), iii) management and colleagues (i.e., leadership style, management behaviours, co-worker behaviours, inspections, sanctions, accident reducing measures, training, safety policies and procedures, ecc.), iv) employee characteristics (i.e., age, gender, education, tenure/experience, safety knowledge, work-life balance, marital status, children, lifestyle, ecc.), v) external (i.e., law and legislation, governmental bodies, economic factors, insurance, costs of safety, ecc.), vi) performance (i.e., safety performance, safety compliance, safety participation, organizational performance, financial performance, environmental performance, ecc.), and vii) safety outcomes (i.e., incidents, accidents, injuries). These seven clusters constitute a suitable framework to identify the possible determinants of workplaces accidents since Cornelissen *et al*. (2017) considered both theoretical and empirical studies and included determinants which have received so far little attention in previous models (e.g., external factors).

As emphasized by Cioni and Savioli (2016), workplace accidents are the result of a process that involves different and multifaceted determinants; our work aims to enrich the literature by investigating the key macroeconomic determinants of workplace accidents, both at European and Italian levels, in an attempt to document the relationships between occupational accidents and economic, territorial and production-system factors affecting workplace risk. Differences in occupational, safety and health (OSH) performance are not likely to be the result of firms' intrinsic characteristics alone, but rather of their interaction with social, political, regulatory, and economic contexts which are therefore investigated.

In order to reduce and contrast the risk of occupational accidents, the Italian initiative ISI of the National Institute for Insurance against Accidents at Work (INAIL) appears to be, since 2010, a unique example in Europe of a direct aid (in the form of a financial grant) for promoting enterprises' investments oriented to enhance the level of safety and health in the workplace. Broadly speaking, the main target of this aid-scheme is to support SMEs' investments in health and safety, prioritizing those operating in high-risk sectors. Investments can be related to both machineries and organizational models. In this context, our work can be seen also as an empirical validation check, at a macro level of analysis, on the adequacy of the specific policy design adopted by INAIL (policy tuning, policy orientation). Is the policy oriented to exert an effect on the most relevant determinants of occupational accidents?

Based on this strand of literature, the aim of the paper is twofold. First, grounding on a model specification that combines productive system characteristics and socio-economic controls, our empirical analysis investigates, at a macro level of analysis, the main determinants of occupational accident rates, aiming to disentangle European cross-country heterogeneity, within the business cycle theoretical framework. Secondly, we deepen the study of the relationship between the European country heterogenous growth trends and occupational accidents, investigating the existence of a nonlinear relationship between accidents' rate and per capita GDP increases, for which the accidents' rate might first grow and then fall. Our empirical analysis relies on a panel dataset composed by 27 European countries, for a time span of 9 years (2010-2018), and we employ alternative econometric approaches (OLS pooled, panel random- and fixed- effects model, system-GMM and semiparametric fixed effects model). The remainder of the manuscript is organized as follows. In section 2, we introduce the data, while section 3 presents our econometric methodology. Estimation results are presented and discussed in section 4. Section 5 outlines our conclusions and policy implications.

2. Data

Our panel dataset is composed by 27 European countries for 9 years (2010/2018): Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom. The data is obtained by Eurostat. Table 1 presents a summary of the variables that we use in our estimations.

Dependent Variable

The dependent variable in the regression model is the incidence rate of workplace accidents resulting in the number of serious accidents per 100,000 persons in employment. In particular, the numerator is the number of accidents that occurred during the year. The denominator is the reference population (i.e., the number of persons in employment) expressed in 100,000 persons. An accident at work is defined as 'a discrete occurrence in the course of work which leads to physical or mental harm1. If the accident does not lead to the death of the victim, it is called a 'non-fatal' (or 'serious') accident, and it is intended involving more than 3 calendar days of absence from work.

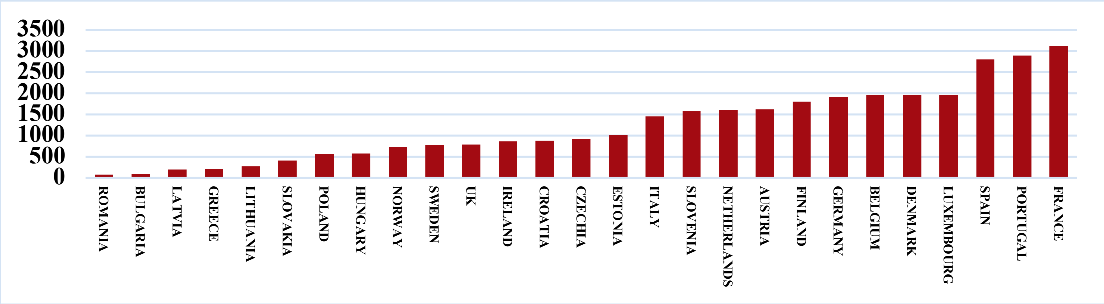
Table 1: Variables description

Variables	Description	Source	Unit
Dependent variable			
Occupational accidents rate	The indicator is calculated as the number of serious accidents per 100,000 persons in employment (in total business economy, repair of computers, personal and household goods, except financial and insurance activities)	Eurostat	Percentage
Productive-system explanatory variables			
Employment risk	The indicator is defined as the sum of the employees working in sectors with high accidents risk (mining and quarrying, construction, and transport) per the total persons in employment (in total business economy, repair of computers, personal and household goods, except financial and insurance activities)	Eurostat	Index
Large firms	The indicator is defined as the number of large firms (250 persons employed or more) per total number of firms in the country. Firms are counted in total business economy, repair of computers, personal and household goods, except financial and insurance activities	Eurostat	Percentage
Temporary contracts	Share of the employees from 15 to 64 years of age with a temporary contract	Eurostat	Percentage
Socio-economic explanatory variables			
GDP per capita	The indicator is calculated as the ratio of real GDP to the average population of a specific year. GDP measures the value of total final output of goods and services produced by an economy within a certain period of time	Eurostat	Euro
Secondary Education.	Share of the population with at secondary education attainment per inhabitants	Eurostat	Percentage
Fixed investment/GDP	Gross fixed capital formation as a percentage of gross domestic product	Eurostat	Percentage
Unemployment	Share of the population of persons from 15 to 74 years of age (16 to 74 years in ES, IT and the UK) unemployed	Eurostat	Percentage
Other territorial explanatory variables			
Crime Index	The indicator is calculated as the number of thefts per hundred thousand inhabitants	Eurostat	Ratio

[1] It includes all accidents in the course of work, whether they happen inside or outside the premises of the employer, on the premises of another employer, in public places or during transport (including road traffic accidents or accidents in any other mean of transportation) and at home (such as during teleworking). It also includes cases of acute poisoning and wilful acts of other persons; it excludes: accidents on the way to or from work (commuting accidents); deliberate self-inflicted injuries; occurrences caused solely by a medical condition (such as heart attack or stroke) that occurred during work, i.e. which were not (at least partially) caused by the occupational activity of the victim; accidents to members of the public, for example family members of a worker who are not working; and occupational diseases. https://ec.europa.eu/eurostat/cache/metadata/en/hsw_acc_work_esms.htm

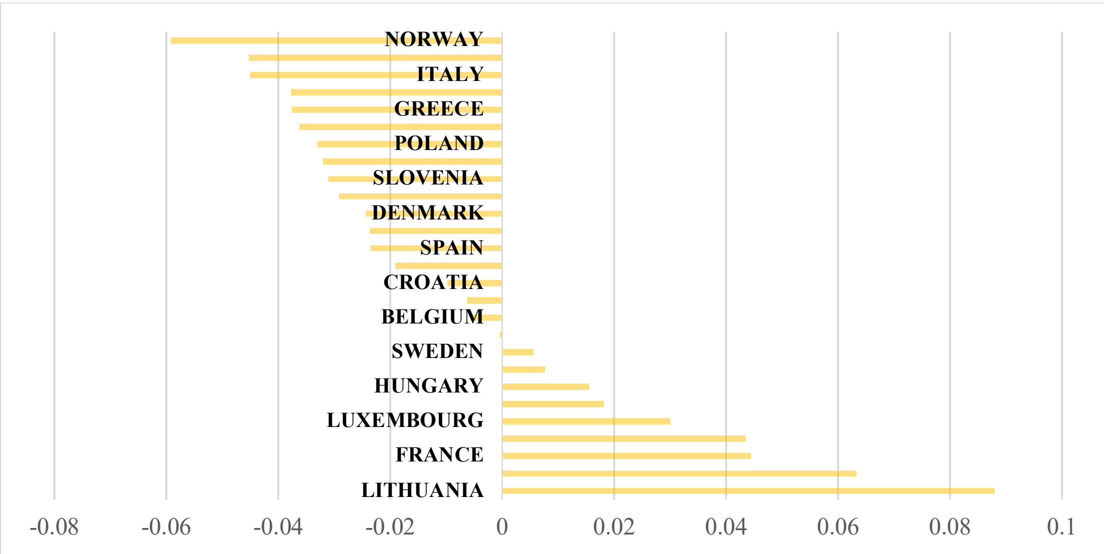
Figures 1 and 2 illustrate, respectively the occupational accidents rate, and the average rate of change of occupational accidents rate.

Figure 1. Occupational accidents rate by country (mean, 2010-2019)



Source: Eurostat

Figure 2. Average rate of change of occupational accident rate by country (mean, 2010-2019)



Source: Eurostat

Figure 1 shows that the top five countries by occupational accidents rate are: France, Portugal, Spain, Luxembourg, and Denmark. By contrast, the last five countries for the same indicator are: Romania, Bulgaria, Latvia, Greece, and Lithuania. But we can obtain further information from observing the time period average rate of the change of occupational accident rate (Figure 2). In this case, the best five performances are recorded by Norway, Ireland, Italy, Netherlands, and Greece. Instead, the worse five performances are recorded by Lithuania, Latvia, France, Romania, and Luxembourg.

Independent Variables

We include a set of explanatory variables, which are divided in three macro-categories: production-system, socio-economic, and other territorial variables. The independent variables were chosen according to those most commonly used in the economic literature on workplace safety, accident and injury research, and they are described below.

Production-system variables

A substantial part of the literature focuses on the relationship between accidents (non-fatal) at the workplace and types of worker contracts (Lopez *et al*., 2008). Dupré (2001) found that, in European countries, the risk of accidents for temporary workers who had been employed for less than two years was particularly high in the construction, health and social sectors. Fabiano *et al*. (2008), using Italian data for the period 2000–2004, show that workers supplied by temporary-help agencies suffer a higher injury frequency index than direct hire employees, due to lack of experience, insufficient specific knowledge, and inadequate training. Virtanen *et al*. (2005) find that temporary workers may have a higher risk of psychological morbidity and work-related injuries as compared to permanent workers. However, Benavides *et al*. (2006) find that, even though temporary workers seem to have a higher risk for work related injuries than permanent workers, after controlling for the length of employment the probability of accidents is quite similar in both groups. The firm size is also considered a relevant variable able to exert a significant impact on the level of occupational risk (Fabiano et al., 2004) finding an inverse correlation between the frequency index of workplace accident and firm size.

In literature a great deal of agreement exists on the type of economic sector which plays a determining role in occupational accident risk levels: this is confirmed by the fact that the differences found in this respect between sectors persist even when controlled for differences in the context between clusters of countries (Lenaerts *et al*., 2022). The sectoral perspective is of importance particularly for the study of risks related to the physical environment (Leigh *et al.*, 1990, 1989; Maiti and Bhattacherjee, 1999; Maiti *et al*., 2001, 2004; Haslam *et al*., 2005; Khanzode *et al*., 2012, 2011), which depend on the production process, the materials used, the equipment typically used in an industry, as well as the activities carried out during the work activity (Eurofound, 2012; Wadsworth and Walters, 2014, Lenaerts *et.al*, 2022). This focus is also relevant in view that physical health risks remain the strongest predictor of injuries for those employed in manual jobs (Kubicek *et al.*, 2019; Toch *et al*., 2014).

Intersectoral differences in terms of activities and tasks performed by workers are also directly related to the occupational structure of each sector. In particular, sectors dominated by blue-collar employments, such as construction, agriculture, industry and transport, typically have less secure physical environments; in contrast, sectors dominated by white-collar occupations, such as financial services, education and public administration, have better levels of physical environment (Lenaerts *et al*., 2022). Therefore, while sectors dominated by occupations with a higher level of education and generally higher labour income are subject to OSH risks more related to psychological factors (such as stress, and anxiety), the so-called blue-collar will be subject to a higher risk of accidents (Dorman, 2000).

Socio-economic variables

Since the pioneering study by Kossoris (1938) on the relationship between occupational accidents and the business cycles, several studies (Ussif, 2004; Davies *et al*., 2009; Fortin *et al*., 1996) have found a pro-cyclical relation between the business cycle and the occupational injuries rates, showing that the number of accidents tends to increase during economic upswings and vice versa (Robinson, 1988; Nichols, 1991; Fabiano *et al*., 1995); periods of economic slow-downs may accompany a reduction in the number of injuries. Furthermore, macroeconomic indicators, such as gross domestic product (Asfaw *et al*., 2011) or unemployment rate (Brooker *et al*., 1997) have been primarily used to study their respective incidence on occupational accidents. Other economic characteristics such as unemployment rate and labour and social-insurance legislation (Blank *et al*., 1996a) are also considered relevant variables. Some authors have suggested that workers tend to underreport minor injuries during a recession (Boone and van Ours, 2006), which reduce the official number of minor injuries that they report in times of crisis.

Territorial variables

The number of thefts is taken as a proxy for the level of crime within a given country. The underlying hypothesis is that a higher level of crime is related to lower OSH compliance by firms. Regulation and compliance might have an impact on OSH levels and this is demonstrated in several empirical studies. Viscusi (1986), for instance, estimates a statistically significant impact of OSH regulation on lost working days due to accidents. Weil (1996), on the other hand, investigates the effect of regulation on firm compliance, as measured by the number of violations of expected standards. In particular, the work investigates the effect of inspections - one of the main control instruments in OSH regulation

- which impose fines and penalties for violations. One of the main outcomes of this study shows that compliance decisions would be made on the basis of potential, rather than actual, penalties. Concerning the role of the sequence and frequency of inspections on the compliance of firms with OSH regulations, Ko *et al.* (2010) find that from the first to the second inspection there is at most a 31% drop in the number of violations (i.e., higher level of compliance), with a smaller drop in the case of serious violations; furthermore, the effect of repeat inspections on serious violations is greater in planned inspections than in other types of inspections.

Table 2 provides an overview of the selected variables and their summary statistics. A cursory look illustrates significant heterogeneity in our variables.

Table 2: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
OA Rate non-fatal	243	1226.776	887.779	47.97	3458.28
Total OA Rate	243	1229.107	887.657	52.88	3461.02
Employment Risk	243	.351	.073	.192	.497
Large Firms	210	.002	.001	.001	.005
Temporary Contracts	243	15.093	9.788	1.8	46.9
Per capita GDP	243	27166.46	18113.98	5050	83470
Secondary Education	243	48.021	11.38	18.8	71.1
Fixed Investments/GDP	242	20.707	3.502	10.77	35.81
Unemployment	243	9.335	4.909	2.2	27.5
Crime Index	243	1490.213	1055.366	220.99	5282.09

The research assumption is that work safety is a complex phenomenon influenced by both micro (individual-related, job-related) and macroeconomic factors (GDP, unemployment), which should be analyzed comprehensively. Our main contributions are: i) to extend the literature in this vein by understanding the main macroeconomic determinants of the incidence of occupational accidents; and ii) to test the existence of a non-linear relationship between the occupational accident rate and the GDP level, while controlling for production-system characteristics and unobserved heterogeneity. On this background, we test for two main hypotheses:

- *Hp1*: Territorial heterogeneity of workplace accidents, at both European and Italian level, can be explained by recurring to a macro level of analysis, within the business cycle theoretical framework. Moreover, the trade-offs between safety at the workplace and production changes to income have been studied in the literature (for a comprehensive review see de la Fuente *et al*., 2014, and Asfaw *et al*., 2011). However, the existence of a possible non-linear relationship between occupational accidents and real per-capita GDP has not been tested

- *Hp2:* A non-linear and non-monotonic relationship (Occupational Accidents Kuznets Curve - OAKC) between the occupational accident rate and the GDP level emerges while controlling for production-system, institutional and macroeconomic characteristics.

3. Econometric Methodology

Since Hartwig's *et al*. (1997) cross-country contribution, an extensive stream of literature has deepened the relationship between workplace accidents (or workers compensations) and the business cycle. The main insight in the background of these analyses is that macro-economic trends can affect the drivers and frictions of occupational accidents. To substantiate this hypothesis several empirical works (Hartwig *et al*., 1997; Brooker *et al*., 1997; Ussif, 2004; Boone and van Ours, 2006; Davies *et al*., 2009; Asfaw *et al*., 2011) find evidence of a correlation between occupational accidents rates and major macro-economic indicators (GDP, fixed investments, unemployment rate).

In the vein of this background, in order to analyze the heterogeneity of the occupational accident phenomenon at the European territorial level (*Hp*1), this paper aims to extend this perspective by including, besides to the main business cycle indicators, also the productive system and institutional characteristics of the EU-27 countries included in our panel. In this context, we first start by conducting a correlation analysis that tests the presence of a link between the annual occupational accidents and the main countries' productive characteristics, controlling for business cycle indicators and institutional characteristics.

The OLS estimation equation takes the following log-log form:

$$OA_{it} = \beta_0 + \beta_1 Xpsc_{it} + \beta_2 Zbc_{it} + \beta_2 Utv_{it} + T_t + FE_i + \varepsilon_{it} \qquad (1)$$

where, the subscripts i and t represent respectively the country and the time period. All variables are expressed in natural logarithms. *OA* is the number of occupational accidents rate measured as the number of serious accidents per 100.000 persons in employment, *X* is a vector of countries' productive system characteristics (employment risk, large firms, temporary contracts), *Z* is a vector of business cycle controls (per capita GDP, secondary education, fixed investments over GDP, unemployment), and *U* is a vector of other territorial variables (crime index). Finally, *T* and *FE* are, respectively, years and geographical fixed effects, ε is the time-varying error term which stands for a well-behaved error term distributed IID ($0, \sigma^2$).

This first approach provides the estimates of the pooled OLS, and the panel fixed (FE) and random (RE) effects models. In order to choose between the fixed and random estimate, both the Breusch-Pagan Lagrange Multiplier Test (1980) and the Hausman Test (1978) reveal that the fixed effects model is the most appropriate one. The risk of hysteresis in the perpetration of accidents at work has raised the attention on the phenomenon that todays' occupational accidents rate can be related to previous ones. Countries past occupational accidents may indeed affect current workplace injuries. For instance, a countries' occupational accident rate in the previous year can explain the level of adherence to occupational safety regulations in the previous year, which in turn can explain a low standard in occupational safety policy enforcement that can determine in the following year a higher level of occupational accidents.

For these reasons, the relevance of a dynamic path associated to occupational accidents rates suggests that OLS coefficients could be inconsistent due to the correlation of OA_{t-1} and the error term, even implementing a first difference approach. Therefore, we complement the standard panel approach with a dynamic panel data analysis (Holtz-Eakin, Newey and Rosen, 1988; Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). With the implementation of an auto-regressive approach, we are able to enhance the accuracy of the OLS estimates and to include the entire history and transition over time of our model.

In our case, given that the panel units are larger with respect to the time periods, we opt for the system-GMM estimator (Arellano and Bover, 1995) that is more efficient (Baltagi, 2005) than the difference-GMM estimator (Arellano and Bond, 1991). Our choice is also confirmed by comparing the magnitude of the coefficients of the lagged dependent variable from the difference- and system-GMM, with those obtained from the pooled OLS and the panel fixed effects (P-FE).

We test *Hp*1 by also dealing with the dynamic and simultaneity problems arising by the hysteresis of occupational accidents. In particular, we estimate the baseline specification model in equation (1) through a system-GMM (Arellano and Bond, 1991; Arellano and Bover, 1995) by also including on the right-hand side the lagged dependent variable. The system-GMM estimation takes the following equation form:

$$OA_{it} = \beta_0 + \beta_1 OA_{it-1} + \beta_2 Xpsc_{it} + \beta_3 Zbc_{it} + \beta_4 Utv_{it} + \eta_i + \xi_t + \varepsilon_{it} \qquad (2)$$

All variables are expressed in natural logarithms. The subscripts i and t represent the country and the time period, respectively. On the right-hand side of equation (2), the explanatory variables are the same of previous equation (1) plus the lagged dependent variable (OA_{t-1}) which was included into the model in order to identify the persistency in the dynamics of occupational accidents; η_i is a country fixed effect and ξ_t a time fixed effect; ε_{it} stands for a well-behaved error term distributed IID *(0, σ^2).*

The system-GMM estimator (Arellano and Bond, 1991; Arellano and Bover, 1995) controls for both time-invariant country specific effects and endogeneity criticalities that arise from the lagged value of occupational accidents rate. The validity of the instruments used are tested by the Sargan (1958) test of over-identifying restrictions to examine the consistency of the instruments and by the Arellano and Bond (1991) test for the serial correlation of the disturbances up to the second order.

In the subsequent stage of the analysis, we provide an insight on the link between occupational accidents and growth by testing the existence of a non-linear and non-monotonic relationship *(Hp2)*. We believe that advances in technology (*i.e.,* Industry 4.0) can provide solutions able to enhance workers' health, safety, and wellbeing, and that are able to allow labor force to shift from low- to high- productivity sectors. Thus, countries that have exploited new technologies displace, with respect to the others, higher levels of GDP potentially justifying a cross-country inverted-U shaped relationship between OA and GDP. In this perspective, we start by estimating through pooled OLS, fixed and random effects model the following equation:

$$OA_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + T_t + \varepsilon_{it} \qquad (3)$$

where, all variables are again in natural logarithm and *i* and *t* represent the country and the time period, respectively. The other elements of the equations have been set out above and are self-explanatory.

We then estimate equation 3 by recurring to the following system-GMM estimation:

$$OA_{it} = \beta_0 + \beta_1 OA_{it-1} + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + T_t + \varepsilon_{it} \qquad (4)$$

Finally, in order to ascertain the robustness of our GDP quadratic specification, we also implement the alternative two-stage semiparametric fixed effects additive model (Baltagi and Li, 2002):

$$OA_{it} = \beta_0 + \beta_1 Xpsc_{it} + \beta_2 \boldsymbol{T_{it}} + g(GDP_{it}) + \nu_{it} \qquad (5)$$

Where unlike previous models, GDP enters the model nonlinearly. All variables are again expressed in natural logarithms. The specified additive model is built in order to satisfy the stochastic equicontinuity condition and is pointwise asymptotically normal. Thus, it achieves the standard one- dimensional rate of convergence and has the same asymptotic accuracy as if the nuisance terms were known with certainty. Furthermore, for the parametric component, the estimates are asymptotically normal. Note, we estimate *g (·)* using b-spline (k = 4). In the parametric part of the estimation, we include the previous set of controls *Xpsc* and the time.

4. Estimation Results

As widely explained in the previous section, our preferred econometric methodology is the GMM-system estimator that allows us to control for dynamics in occupational accidents rates and joint endogeneity of the explanatory variables and for country-specific effects. For comparative purposes we also present results obtained by mean of the pooled OLS estimator, which ignores the presence of country-specific effects and treats all variables as exogenous, and the random effects (RE)/fixed effects (FE) estimators, which controls for the presence of unobserved country-specific heterogeneity. The results of the pooled OLS estimates are presented in Table 3; the panel RE/FE and system-GMM results are displayed in Table 4.

In Table 3, Model 1 shows the results of the baseline model where *occupational accidents rate* is regressed only against the vector of the chosen covariates relative to the productive-system variables, i.e., *employment risk, large firms, and temporary contracts*. In models 2 and 3, the business cycle-related explanatory variables (i.e., *per capita GDP*, *fixed investments/GDP*, *unemployment*) and some other socio-economic controls (i.e., *secondary education, crime*) are added. Overall evidence, at this very first stage of analysis, confirms the consistent effect exerted by all the different sets of covariates on occupational accidents rates, across all the estimates. The obtained positive and highly statistically significant relationships support the argument that higher levels of *employment risk, temporary contracts, per capita GDP*, *unemployment, and crime* may accompany an increase in the rate of occupational accidents. Likewise, the obtained negative and highly statistically significant relationships allow us to hold that higher levels of *large firms, secondary education, and fixed investments/GDP* may drive a reduction in the rate of occupational accidents.

Table 3: Pooled OLS estimations

Variables	Model 1 OLS	Model 2 OLS	Model 3 OLS
	OA Rate	OA Rate	OA Rate
Empl. Risk	1.583*** (0.337)	2.321*** (0.310)	2.537*** (0.292)
Large Firms	-0.565*** (0.125)	-0.183 (0.116)	-0.242** (0.109)
Temp. Contracts	1.225*** (0.105)	0.532*** (0.136)	0.531*** (0.127)
GDP_PC		0.905*** (0.125)	0.724*** (0.121)
Secondary Edu.		-0.892*** (0.227)	-0.532** (0.221)
Fixed Investments/GDP		-0.531 (0.326)	-0.598* (0.304)
Unemployment		0.469*** (0.145)	0.500*** (0.136)
Crime Index			0.414*** (0.075)
Year	Yes	Yes	Yes
Cons.	1.903** (0.852)	1.798 (2.273)	-0.731 (2.161)
F-stat	14.42***	23.72***	27.20***
R^2	0.41	0.62	0.67
Groups	27	27	27
Obs.	210	210	210

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

As it is showed in Table 4, the obtained panel fixed/random effects models and the system-GMM results confirm, with a high degree of reliability, that the employed approach to the assessment of the occupational accidents rate is adequate. The negative relationship with the *firms' large size* is consistent with the hypothesis by main literature (Fabiano *et al*., 2004) according to which the number of accidents declines with the increase of company's size. It is often argued (Salminen, 1993, 1998) that large companies have fewer accidents since they have more knowledge and better financial resources for workplace health and safety investments. With regard to the level of education, the negative and statistically significant relationship is in line with the relevant literature (Cioni and Savioli, 2016).

Table 4: Panel Fixed/Random effects model and system-GMM

Variables	Model 1 FE	Model 2 RE	Model 3 SYS-GMM
	OA Rate	OA Rate	OA Rate
OA_Rate (t-1)			0.267*** (0.022)
Large Firms	-0.397** (0.194)	-0.307** (0.136)	-0.197*** (0.073)
Temporary Contracts	0.276** (0.110)	0.401*** (0.085)	0.008 (0.057)
Per capita GDP	1.016** (0.462)	0.810*** (0.162)	0.089 (0.349)
Secondary Education	0.145 (0.321)	-0.236 (0.256)	-0.244** (0.113)
Fixed Investments/GDP	-0.555*** (0.187)	-0.534*** (0.185)	-0.513*** (0.143)
Unemployment	-0.201* (0.111)	-0.250*** (0.093)	-0.145** (0.065)
Crime Index	0.157** (0.069)	0.215*** (0.066)	0.107** (0.050)
Year	Yes	Yes	Yes
Cons.	1.903** (0.852)	2.651 (1.936)	1.798 (2.273)
F-stat or Wald χ^2	4.38***	151.67***	168.69***
R^2	0.65	0.72	0.62
AR(1) Pr > z			0.1036
AR(2) Pr > z			0.2780
Sargan test			19.60
Groups	27	27	27
Obs.	210	210	210

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

As we can observe, in the system-GMM model, the coefficient of the lagged dependent variable is positive and highly statistically significant suggesting that occupational accidents rate displays persistence over time, i.e., the dynamics and current complex workplace safety conditions can subsequently develop more accidents. The negative and highly statistically relationship with *fixed investments/GDP* confirms that occupational accidents are influenced by economic cycles; thus, higher levels of fixed investments/economic upturns might reduce the number of occupational accidents. The inverse relationship with unemployment rate is also consistent with some relevant literature (i.e., Ferguson *et al*., 1985; Rasmussen, 1987; Vredenburgh, 2002; Boone *et al*. 2006; de la Fuente *et al*., 2014): the idea behind this finding is that, if unemployment is high, workers are reluctant to report accidents because they fear that employers will hold this against them. From a policy perspective this result implies that, in times of high unemployment, safety auditors should encourage people to report accidents. Finally, the estimates highlight a positive relationship between occupational accidents rate and crime, thus suggesting, in line with our hypothesis, that countries with a higher level of crime are exposed to lower OSH compliance by firms, resulting in an increase of occupational accidents.

Ultimately, to test *Hp*2, we check for the existence of a non-linear and non-monotonic relationship between the occupational accident rate and per capita GDP level, employing the same set of estimation strategies. Our final estimation results are presented in Table 5.

Table 5: Testing the existence of a non-linear and non-monotonic relationship between GDP and occupational accidents rate

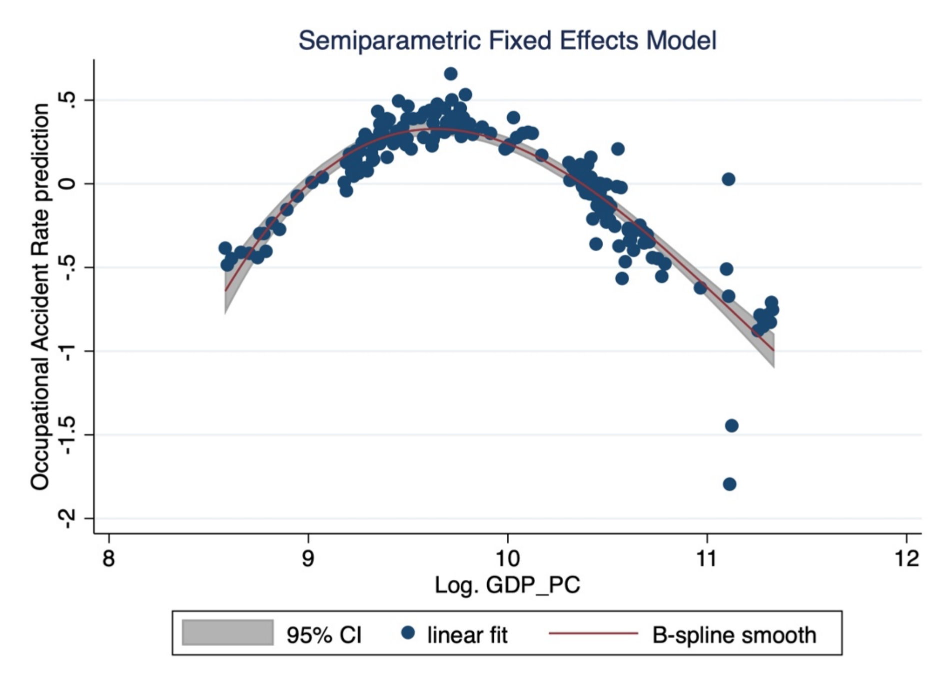
Variables	Model 1 OLS	Model 2 FE	Model 3 RE	Model 4 SYS-GMM
	OA Rate	OA Rate	OA Rate	OA Rate
GDP_PC	19.707*** (1.678)	12.468*** (2.050)	10.663*** (2.238)	6.370*** (1.230)
GDP_PC^2	-0.939*** (0.084)	-0.569*** (0.104)	-0.464*** (0.115)	-0.334*** (0.061)
L. OA_Rate				0.426*** (0.005)
Year	Yes	Yes	Yes	Yes
Const.	-95.840*** (8.340)	-60.609*** (10.146)	-53.090*** (10.992)	-26.330*** (6.146)
F-stat or Wald χ^2	38.77***	9.07***	127.23***	6803.97***
R^2	0.61	0.54	0.59	-
Groups	27	27	27	27
Obs.	210	210	210	210

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

We find evidence of an inverted U-shaped relationship between the rate of OA and the real per capita GDP in a time of transition towards a new technological paradigm in Europe. The results are robust to endogeneity linked to the transitional dynamics and persistency of the OA rate over time. The transition towards the new Industry 4.0 paradigm, currently in progress in the time period of our analysis, generates a skill biased technological change (SBTC) that, if exploited, could provide solutions able to enhance workers' health, safety and wellbeing, reducing OA rates.

To provide a further robustness check to the reliability of the quadratic specification, we estimate equation 5 using a semiparametric fixed effects estimator (Baltagi and Li, 2002). Therefore, we estimate the occupational accidents rate allowing the GDP to enter the model nonlinearly. In Figure 3, we plot the nonparametric b-spline estimate of *g(GDP)*; we can observe that the nonparametric estimate (red line) depicts a clear inverted U-shaped curve. This result provides an "unconstrained" sounding reassessment of the non-linear relationship between GDP and occupational accidents rate obtained with the implemented parametric approaches.

Figure 3: Semiparametric Fixed effects model (Baltagi and Li, 2002)



5. Conclusions

Our results can give rise to some relevant policy implications. Overall, our cross-country analysis reveals that the heterogeneity of OA rates is significantly correlated to productive systems characteristics, to the business cycle and to some other territorial variables. Based on our findings, the improvement of both macro- and micro- economic conditions should be the priority for new policies on work safety. In particular, policy makers and employers should be aware of the correlation between the business cycle and the occurrence of workplace accidents, which calls the need for additional safety measures during economic expansions. Although definitive conclusions cannot be drawn from the results of this study, some interesting insights do emerge. Firstly, in relation to the production system controls we can highlight the following findings: the higher is the share of large firms, the lower is the OA rates (confirming previous empirical literature); the existence of a positive, even though feeble, correlation between temporary contracts and OA (in line with Cioni and Savioli, 2016); the higher is the employment risk attached to the productive sector, the higher is the OA rate. Secondly, in relation to the business cycle controls: the OA rate increases with real per capita GDP (confirming previous empirical literature); the higher is the level of education, the lower is the OA rate (Fotta and Bockosh, 2000; Jeong, 1999; Kletz, 1993; de la Fuente *et al*., 2014, Cioni and Savioli, 2016); the higher is the propensity to invest in fixed assets, the lower is the OA rate (Blank *et al*., 1996b; Sari *et al*., 2004; Aswaf *et al*., 2011). Finally, the estimations reveal that countries with a higher level of crime generate lower OSH compliance by firms, thus determining an increase in the number of occupational accidents.

Taken all together, our findings imply that OSH targets, besides pursuing the aims established in principle 10 of the European Pillar of Social Rights *(Healthy, safe and well-adapted work environment and data protection)* are crucial drivers for improving the sustainability and competitiveness of the EU economy. In this vein, providing a direct financial grant to SMEs for both tangible and intangible OSH investments, the overall policy design of the Italian INAIL ISI initiative appears to be well grounded on the theoretical economic foundations and to potentially generate additionality on SMEs' investments in OSH, able to generate gradual reductions of OA rates. In this perspective, our findings seem to suggest the need to recalibrate the mix of occupational health and safety policies shifting from regulatory and indirect policy tools towards a system with a wider use of SMEs direct investment support in OSH with the financial support of the actual National Recovery and Resilience Plans.

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