A life-cycle model of risk-taking on the job

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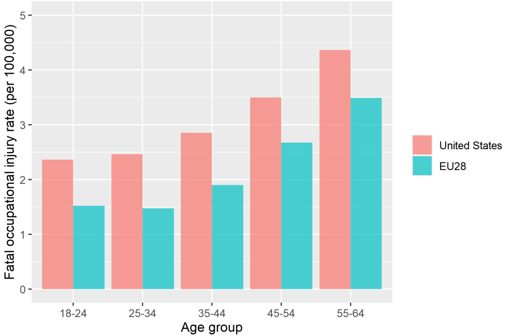
Motivation

- fatal work-related injuries and diseases are prevalent and costly
  - US: 58 600 deaths at \$52 billion (Leigh 2011)
  - EU28: 200 000 deaths at 1.5% of GDP (EU-OSHA 2017)
  - global: 2.8 million deaths at 2.1% of GDP (EU-OSHA 2017)
- work-related mortality risk is higher for older individuals
  - more likely to die from diseases that can be attributed to work-related factors (Hämäläinen et al. 2007, 2011)
  - also more likely to encounter a fatal occupational injury (→ next slide)
- in light of this, ongoing aging of the workforce and later retirement may further increase prevalence and costs of work-related deaths
- develop structural model to understand how **risk-taking incentives change over the life-cycle** and how these shape the observed age pattern of **fatal occupational injuries**

Age-profile of fatal occupational injuries



Average fatality rate by age group in the US and EU28, 2011–2018. Data source: BLS, Eurostat.

- robust to controlling for occupational composition and demographic characteristics (sex, race, ethnicity, education, health) Poisson regressions

Age-profile of fatal occupational injuries

- increasing age pattern often attributed to deterioration of physical and mental capacities (Ilmarinen 2008; Crawford et al. 2019)
- at the same time, aging individuals become more risk averse throughout all domains (Dohmen et al. 2011; Rolison et al. 2014, Josef et al. 2016)
- workers do not seem willing and/or able to counteract the increasing fatality risk at the workplace more strongly
  - unawareness, inertia
  - no influence on working conditions
  - reduced possibilities to switch to safer jobs
- we show that the observed pattern can be perfectly replicated in a **rational expectations general equilibrium model** with a **frictionless labor market** where workers can **flexibly adjust** their mortality risk

Key results

- in our model, on-the-job mortality increases in age due to two effects:
  1. reducing mortality becomes more costly because of higher forgone wages
  2. the benefit of reducing mortality decreases due the decreasing value of life (Murphy and Topel 2006)
- calibrating the model to the US, the model closely replicates the observed age profile of the fatality rate from occupational injuries
- also investigate the role of uninsurable income shocks and find that "lucky" individuals choose lower risk, especially in their late career
- a reduction in general mortality and a higher retirement age are found to reduce on-the-job mortality of all workers, especially for older workers

Most closely related literature

- Partial equilibrium life-cycle models with endogenous work-related mortality
  Galama and Van Kippersluis (2019), Strulik (2022)
- Search and matching models with endogenous work-related mortality
  Kerndler (2023)
- Value of a statistical life
  Rosen (1986), Viscusi and Aldy (2003), Kniesner and Viscusi (2019), and many more papers by Viscusi

The Model

Individuals

- are in one of **three labor market states**: employment ($\mathcal{L}$), unemployment ($\mathcal{U}$), retirement ($\mathcal{R}$)
  - unemployment = employment with labor productivity of zero
  - start in unemployment at age $t = 0$ and retire at exogenous age T_R
  - during work life, stochastic transitions between employment and unemployment according to a Markov process
- **mortality risk** is captured by the conditional survival probability

$$\boldsymbol{\pi}_t(x) = \hat{\pi}_t \cdot \begin{cases} 1 - m_t & x = \mathcal{L}, \\ 1 - m_U & x = \mathcal{U}, \\ 1 - m_R & x = \mathcal{R} \end{cases}$$

  - $\hat{\pi}_t$ ... exogenous age-specific baseline conditional survival rate
  - m_t, m_U, m_R ... additional mortality rates dep. on labor market status
  - m_U and m_R are exogenous, **probability of dying on the job $\boldsymbol{m_t}$** is determined endogenously

Consumption-saving decision

- an agent of age t with assets a_t and labor market state $x \in \{\mathcal{L}, \mathcal{U}, \mathcal{R}\}$ chooses $c_t|x$ to maximize

$$W_t(a_t, x) = U(c_t|x) - \mathbf{1}_{\{x=\mathcal{L}\}}\chi(1 - \boldsymbol{\pi}_t(x)) + \beta\boldsymbol{\pi}_t(x)\,\mathbf{E}_t\left[W_{t+1}(a_{t+1}, x')|x\right]$$

$$\text{s.t.} \quad a_{t+1}|x = \begin{cases} \frac{R}{\boldsymbol{\pi}_t(x)}(a_t + (1-\tau)w_t(m_t) - c_t|x) & x = \mathcal{L}, \\ \frac{R}{\boldsymbol{\pi}_t(x)}(a_t + z_t - c_t|x) & x = \mathcal{U}, \mathcal{R}. \end{cases}$$

  - employed individuals receive risk-dependent net wage $(1-\tau)w_t(m_t)$ determined on the labor market; others transfer z_t from government
  - gross interest rate R is determined on the capital market
  - perfect annuity market $\Rightarrow$ effective interest rate is $R/\boldsymbol{\pi}_t(x)$

- **optimal consumption decisions** follow the Euler equation

$$U'(c_t|x) = R\beta\,\mathbf{E}_t\left[U'(c_{t+1}|x')|x\right]$$

Optimal level of on-the-job risk

- employed individuals additionally decide on the **optimal on-the-job mortality risk m_t**
- the optimality condition is

$$\underbrace{\chi\hat{\pi}_t}_{\substack{\text{immediate loss}\\ \text{from higher disutility}}} + \underbrace{\beta\hat{\pi}_t\,\mathbf{E}_t\left[W_{t+1}(a_{t+1},x')|\mathcal{L}\right]}_{\text{expected loss from dying earlier}} = \underbrace{U'(c_t|\mathcal{L})(1-\tau)w_t'(m_t)}_{\substack{\text{immediate gain from}\\ \text{a marginally higher wage}}}$$

- equivalently in terms of the value of life $\mathsf{VoL}_{t|\mathcal{L}} := \frac{\mathbf{E}_t\left[W_{t+1}(a_{t+1},x')\middle|\mathcal{L}\right]}{U'(c_t|\mathcal{L})}$

$$(1-\tau)w_t'(m_t) = \hat{\pi}_t\left[\frac{\chi}{U'(c_t|\mathcal{L})} + \beta\mathsf{VoL}_{t|\mathcal{L}}\right]$$

Firms

- **representative firm** uses effective labor H and capital K to produce with neoclassical production function $F(K, H)$
- effective labor is

$$H = \sum_{t=0}^{T_R - 1} \int y_t(m_t) L_t(m_t) dm_t$$

  - $y_t(m_t)$ is a worker's **productivity net of the costs of risk prevention**, e.g. slowing-down due to safety procedures or safety gear, downtimes due to machine maintenance or safety trainings
  - $y_t' > 0$ and $y_t'' < 0$, as reducing risk becomes increasingly costly
- firm chooses K and $L_t(m_t)$ $\Rightarrow$ first order conditions:

$$w_t(m_t) = F_H(K, H) y_t(m_t)$$
$$r + \delta = F_K(K, H)$$

Stationary Equilibrium

- individuals and firms follow their optimal decision rules
- the interest rate r clears the capital market
- the wage schedule $w_t(m_t)$ clears the labor market, such that $L_t(m_t)$ equals the mass of age t individuals choosing m_t
- the wage tax τ balances the government budget

Quantitative analysis

Calibration

- calibrate to US economy in 2015
- numerical results are based on simulations of 500 individuals per cohort
- a model period corresponds to a month
- baseline survival follows a Gompertz law, $\hat{\pi}_t = \exp(-\alpha_\pi e^{\beta_\pi (t/12+20)})$
- utility function is isoelastic, $U(c_t) = \frac{(c_t)^{1-\frac{1}{\sigma_c}}}{1-\frac{1}{\sigma_c}}$
- worker's net productivity is isoelastic,

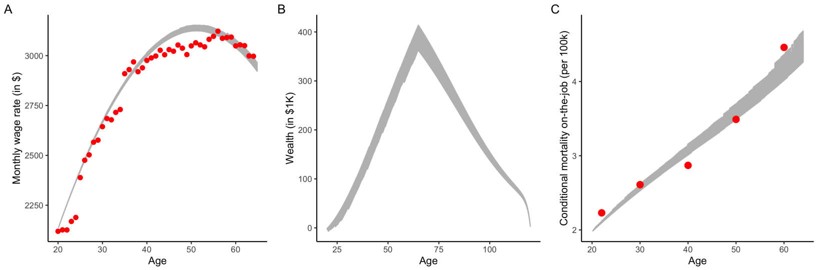
$$y_t(m_t) = \overline{y}_t m_t^{\sigma_y}$$

  - $\sigma_y \in (0,1)$ is the elasticity w.r.t. on-the-job mortality risk m_t
  - $\overline{y}_t = \overline{y} f(t)$ is the exogenous age-productivity profile, where $f(t) = f_0 + f_1 t + f_2 t^2$
  - nothing can be produced without risk, $y_t(0) = 0$, and $y_t(1) = \overline{y}_t$

Parameters

Parameter	Symbol	Value	Remark
(a) Externally set parameters			
Subjective discount factor	β	1	standard
Disutility of work	χ	0	benchmark
Duration of working life (months)	T_R	540	retirement at age 65
Gompertz law for baseline mortality	α_π, β_π	$e^{-12.115}$, 0.08185	Human Mortality Database
Conditional mortality in unemployment	m_U	$1 - 0.993^{1/12}$	Gerdtham and Johannesson (2003)
Conditional mortality in retirement	m_R	$sm_U + (1-s) \times[e^{4.5\times10^{-5}/12} - 1]$	prevent mortality drop at retirement
Job separation probability	s	0.034	Shimer (2005)
Job finding probability	p	0.45	Shimer (2005)
Unemployment benefit replacement rate	ϕ_U	0.4	Shimer (2005)
Pension replacement rate	ϕ_R	0.4	OECD
Output elasticity of capital	α	0.33	standard
Depreciation rate	δ	$1.05^{1/12} - 1$	5% depreciation p.a.
(b) Calibrated parameters			
Intertemporal elasticity of substitution	σ_C	0.8685	targets value of life of $12 million (Kniesner and Viscusi 2019)
Output elasticity of on-the-job mortality	σ_y	0.013	targets avg. occupational fatality rate
Labor productivity (scale)	$\overline{y}$	693.77	targets avg. wage in age group 35–44
Age-profile of labor productivity	f_0	0.2122	targets age-profile of wages
	f_1	3.114×10^{-2}	
	f_2	-2.933×10^{-4}	

Age profiles



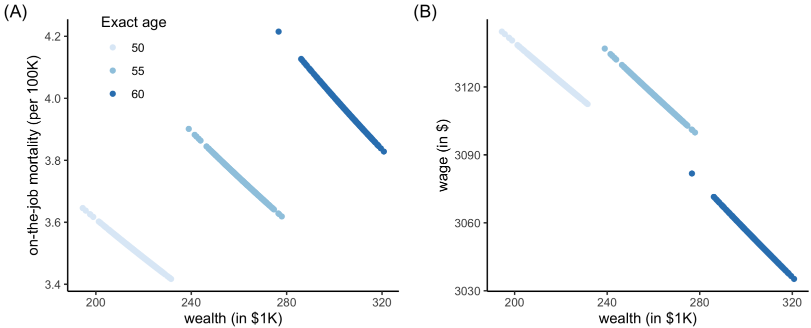
Age profiles of the monthly wage (A), wealth (B), and on-the-job mortality rate (C). Grey areas indicate the range of all simulated profiles. Red points indicate the data. Data source: CFOI, CPS, own sim.

- although not targeted, the model matches the age profile of on-the-job mortality very well; it can be shown that

$$m_t \propto \left[\frac{f(t)}{\hat{\pi}_t \mathsf{VoL}_t} \right]^{1/(1-\sigma_y)}$$

- mortality differentials increase over time due to wealth inequality and the increasing need to save for retirement

Effect of wealth on mortality and wages



- at any given age, wealthier workers choose lower mortality and wages
  - wealth allows to enjoy high consumption even if wage income is low
  - incentive to give up wealth for health increases in age regression table

Value of a Statistical Life

- willingness to pay for a reduction in the fatality rate by 1 in 100 000 workers over a year (Kniesner and Viscusi 2019)
  1. estimate hedonic wage regression $\log(w_{it}) = \alpha_t + \beta m_{it} + \varepsilon_{it}$
  2. compute VSL $= \hat{\beta} \times \bar{w} \times 100\,000$

- estimating VSL from our simulated data:

	Age=All	Age=40	Age=50	Age=60
Regression coefficient ($\hat{\beta}$)	0.0428	0.0516	0.0447	0.0388
Mean monthly wage in \$ ($\bar{w}$)	2 896	2 985	3 134	3 106
VSL in million \$	12.39	15.42	14.00	12.04

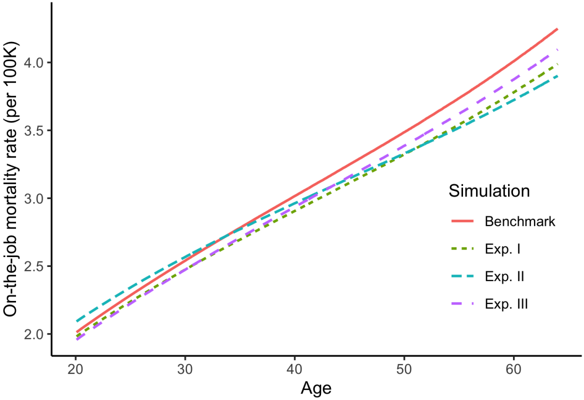
  - mean VSL value lies in range of Kniesner and Viscusi (2019) [targeted]
  - reduction of VSL in age is consistent with Aldy and Viscusi (2008)
  - our model implies that $\text{VSL}_t \propto \text{VoL}_{t|\mathcal{L}}$ for all t

Effects of pension reforms and aging

- how do changes in the pension system or increases in overall life expectancy affect risk-taking on the job?
  - I raise retirement age T_R from age 65 to 70
  - II raise pension replacement rate ϕ_R from 40% to 50%
  - III reduce baseline mortality α_π to increase life expectancy at birth by 2 years
- average on-the-job mortality before age 65 decreases by 2.6–3.8%
  - this is due to a higher average value of life
  - strongest effect on oldest workers
  - younger workers gain less and are even worse off in Experiment II

Effects of pension reforms and aging

Age profiles of on-the-job mortality



Welfare effects

Age	Exp. I	Exp. II	Exp. III
20	7.74	−2.31	33.26
30	8.16	−0.96	37.90
40	8.55	0.39	43.44
50	8.90	1.74	49.85
60	9.14	3.10	56.92

Consumption equivalent variation in % relative to the benchmark case.

Exp. I: higher retirement age; Exp. II: higher pension replacement rate;
Exp. III: lower baseline mortality

Conclusion

- rational expectations general equilibrium model with endogenous choice of on-the-job risk
  - replicates the increasing age profile of occupational fatalities in the US
  - mainly driven by the decreasing value of life
- uninsurable income shocks generate mortality differentials
  - these increase in age due to the increasing need to save for retirement
  - at any given age, wealthier workers choose lower mortality at the expense of lower wages
- policy implications
  - aging of the working population and later retirement can be expected to reduce on-the-job mortality across all ages
  - changing financial incentives of the pension system can have adverse effects on younger workers

Backup slides

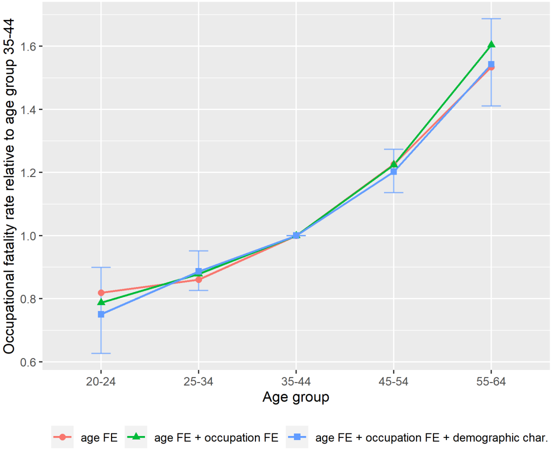
Poisson regression framework

- Census of Fatal Occupational Injuries 2011–2018 (CFOI)
  - number of fatal occupational injuries
  - disaggregated by 5 age groups and 23 occupations (2-digit SOC)
- matched with Current Population Survey (CPS)
  - number of full-time equivalent workers
  - demographic information: sex, race, ethnicity, education, self-employment
- Poisson regressions on 880 occupation-year-age group cells

$$\mathbf{E}[D_{ait}|\mathcal{X}_{ait}] = \mu_{ait} N_{ait} = \exp[\beta_a + \gamma_i + \delta X_{ait}] N_{ait}$$

  - full-time equivalent workers N_{ait}
  - age group fixed effect β_a
  - occupation fixed effect γ_i
  - demographic characteristics X_{ait}

Estimated age gradient of occupational fatality



Estimated age profile of the fatal occupational injury rate. Error bars indicate the 95% confidence interval of the point estimate in the full regression model.

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Poisson regression table

	Dependent variable: fatal injuries		
	(1)	(2)	(3)
age group 20–24	-0.200	-0.238^{***}	-0.287^{**}
age group 25–34	-0.151	-0.129^{***}	-0.120^{**}
age group 45–54	0.204	0.203^{***}	0.185^{***}
age group 55–64	0.428^{**}	0.473^{***}	0.434^{***}
share white workers (non-hispanic)			-1.978
share black workers (non-hispanic)			-2.076
share Asian workers (non-hispanic)			-5.516
share hispanic workers			-1.964
share workers with high school degree			-0.120
share workers with college degree			-0.442
share self-employed workers			0.942^{**}
share male workers			0.384
constant	-10.457^{***}	-11.294^{***}	-9.167^{***}
Controls			
Occupation-fixed effects		✓	✓
Demographic variables			✓
Observations	880	880	880

Notes: Poisson regressions on occupation-year-age group cells. Coefficients are relative to age group 35–44 and can be interpreted as marginal effects on log(mortality rate). Sign. levels: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Descriptive statistics of the four simulations

Variable		Benchmark		Experiment I[a]		Experiment II[b]		Experiment III[c]	
(a) Population characteristics									
Population	N	59 557		59 546		59 558		61 429	
Employed	L	40 228		44 018		40 228		40 450	
Unemployed	U	2 572		2 807		2 572		2 586	
Retired	R	16 757		12 721		16 757		18 392	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
(b) Endogenous variables									
(conditional on being employed and below age 65)									
Probability of dying†									
total	$1-\boldsymbol{\pi}(\mathcal{L})$	28.44	(27.67)	28.56	(27.85)	28.43	(27.66)	24.40	(23.68)
on-the-job	m	0.26	(0.05)	0.25	(0.05)	0.25	(0.04)	0.25	(0.05)
on-the-job mortality rate†	μ	3.11	(0.63)	2.99	(0.57)	3.02	(0.51)	3.03	(0.61)
Wage level	w	2 882	(286)	2 858	(283)	2 822	(279)	2 896	(287)
Worker productivity	y	4 367	(433)	4 330	(429)	4 276	(423)	4 389	(435)
Consumption	c	1 876	(303)	2 026	(352)	1 803	(346)	1 827	(283)
Wealth (in 1 000s)	a	151	(105)	151	(103)	140	(94)	152	(105)
Value of Life (in 1 000s)	VoL	12 003	(1 356)	13 136	(1 327)	11 372	(922)	12 164	(1 350)
Tax rate	τ	0.1896		0.1383		0.2313		0.2049	
Real interest rate	r (in %)	0.14		0.14		0.16		0.13	
(c) Exogenous variables									
Baseline mortality	$\ln(\alpha_\pi)$	−12.115		−12.115		−12.115		−12.275	
Pension replacement rate	ϕ_R	0.4		0.4		0.5		0.4	
Retirement age (years)	$\frac{T_R}{12}+20$	65.0		70.0		65.0		65.0	

Notes: †Values reported per 100 000 individuals. [a] Experiment I: higher retirement age; [b] Experiment II: higher pension replacement rate; [c] Experiment III: lower baseline mortality.

Marginal effect of wealth on mortality and wages

$$\log(m_{it}) = \alpha_m + \beta_m \log(a_{it}) + u_{it}$$
$$\log(w_{it}) = \alpha_w + \beta_w \log(a_{it}) + v_{it}$$

	Dependent variable: log(on-the-job mortality)		
	Age=50	Age=55	Age=60
log(wealth)	−0.347	−0.452	−0.579
Constant	3.028	4.474	6.209

	Dependent variable: log(wage)		
	Age=50	Age=55	Age=60
log(wealth)	−0.005	−0.006	−0.008
Constant	8.106	8.126	8.136

Note: All coefficient estimates have a p value smaller than 0.01. Regressions on simulated data. Our model implies that $\frac{\partial \log(w_{it})}{\partial \log(a_{it})} = \sigma_y \frac{\partial \log(m_{it})}{\partial \log(a_{it})}$

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