The Role of Human Capital in a Highly-Specialized Context:

The Case of High-Volume Orthopaedic Surgery

Sahar Paktinat

Department of Economics, University of Bologna, Italy

PhD Coordinator
Prof. Emanuele Padovani

Supervisor
Prof. Rossella Verzulli

Co-supervisor
Prof. Cristina Ugolini

Public GoMaP Thesis Defence

27 March 2026

Thesis Introduction

- **Orthopaedics** is increasingly central to health systems due to **ageing populations** and **rising demand** for joint replacement.
- Policymakers adopt structural reforms (**centralization**, **outsourcing**, **integration**), but their impact is unclear.
- This **dissertation** studies how **organisational arrangements** affect **outcomes**, comparing urgent (**hip fractures**) and elective (**knee arthroplasty**) care.

Thesis Outline

- Chapter I: **"Does Practice Make Perfect? Panel Evidence from Hip Fracture Surgery in Italy"**, joint with Cristina Ugolini, Rossella Verzulli
  - Minimum volume thresholds for emergency hip fractures
- Chapter II: **"When Private Providers Serve the Public Health System: Evidence from an Integrated Healthcare Model"**, joint with Giulia Guidi, Cristina Ugolini, Rossella Verzulli, Barbara Bordini
  - Public and private differences and knee replacement projections
- Chapter III: **"Hospital Volume and Knee Replacement Outcomes: Implications for Workforce Participation"**, joint with Sverre A.C. Kittelsen
  - Labour market outcomes as quality indicators

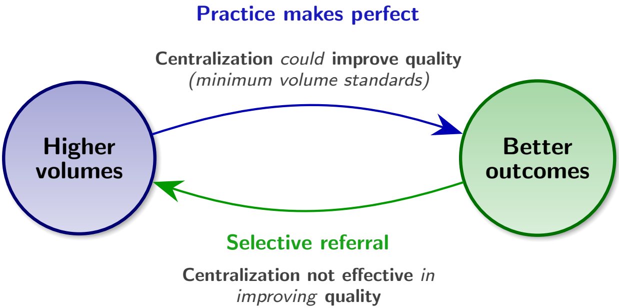
Does Practice Make Perfect?

Panel Evidence from Hip Fracture Surgery in Italy

Introduction

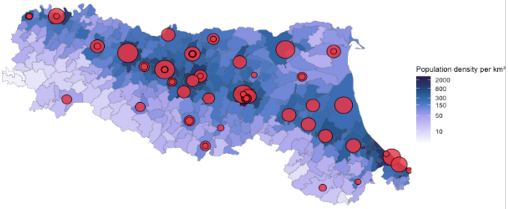
- **Existing literature** shows a **positive association** between the **frequency** a hospital performs a **surgical procedure** and **better patient outcomes** (e.g., Gaynor et al., 2005; Facchini, 2021; Červený, 2023).

- Two possible explanations. **Direction of causality** important for **policy**:



Context and Setting

- **Highly regulated system**: Emilia-Romagna region
- **Emergency care**: hip fracture surgery within 48h $\rightarrow$ Patients **cannot choose** hospital or surgeon $\Rightarrow$ **Selective referral unlikely**
- **Policy**: DM70/2015 imposes **minimum volume threshold** (75 surgeries/year per ward)
- **Research question**: Does higher ward volume reduce **30-day mortality** for hip fracture patients?



Red circles: wards performing hip fracture surgery; overlap = multiple wards per hospital.

Empirical Methodology

- Data: **SDO** linked to the **Mortality register** and the regional surveillance system for surgical site infections (**SIChER**).
- We estimate the effect of surgical experience on patient outcomes using a **multi-way fixed effects model**:

$$y_{iswht} = \beta_0 + \beta_1 \ln(volume)_{iwh,t-1} + X'_{iswht}\beta_2 + \alpha_s + \delta_h + \gamma_t + \varepsilon_{iswht} \quad (1)$$

- Outcome: **30-day mortality** after hip fracture surgery.
- Key variable: **lagged ward-level surgical volume**.
- Controls: patient demographics, comorbidities, fracture type, and weekend admission.
- Fixed effects for **surgeon, hospital, and year** absorb time-invariant heterogeneity.
- β_1 measures how prior surgical volume affects mortality risk.

Lagged surgical volumes and 30-day mortality

	(1)		(2)		(3)		(4)	
Ln(Ward volume)$_{t-4}$	-0.00633	-0.00578						
	(0.00502)	(0.00487)						
Ln(Ward volume)$_{t-12}$			-0.00922	-0.00643				
			(0.00560)	(0.00545)				
Ln(Ward volume)$_{t-24}$					-0.0212**	-0.0167*		
					(0.00915)	(0.00886)		
Ln(Ward volume)$_{t-52}$							-0.0333***	-0.0291**
							(0.0122)	(0.0113)
Patient controls	N	Y	N	Y	N	Y	N	Y
Surgeon FE	Y	Y	Y	Y	Y	Y	Y	Y
Hospital FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
N	10,377	10,377	9,996	9,996	9,327	9,327	7,550	7,550
Bayesian crit. (BIC)	-6373.8	-6684.1	-6173.3	-6468.2	-5508.5	-5804.7	-4429.8	-4660.5
Akaike crit. (AIC)	-6149.1	-6445.0	-5985.8	-6230.2	-5330.0	-5569.1	-4270.5	-4431.9
R^2	0.0571	0.0853	0.0521	0.0810	0.0574	0.0885	0.0648	0.0953

Notes: Sample period: years 2017–2019. Standard errors (in parentheses) are clustered on hospitals. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Effect of past year hospital ward volume thresholds

	(1)	(2)
Past year hospital ward volume (baseline: ≤ 75)		
76–118 surgeries	-0.0556	-0.0558
	(0.0441)	(0.0395)
119–186 surgeries	-0.0690	-0.0657^{*}
	(0.0421)	(0.0378)
198–260 surgeries	-0.0776^{*}	-0.0733^{*}
	(0.0432)	(0.0389)
261–285 surgeries	-0.0910^{**}	-0.0849^{**}
	(0.0428)	(0.0384)
286–330 surgeries	-0.0954^{**}	-0.0898^{**}
	(0.0435)	(0.0392)
≥ 331 surgeries	-0.103^{**}	-0.0940^{**}
	(0.0461)	(0.0432)
Patient controls	N	Y
Surgeon FE	Y	Y
Hospital FE	Y	Y
Year FE	Y	Y
N	7,550	7,550
R^2	0.0640	0.0949
Akaike crit. (AIC)	-4413.7	-4657.3
Bayesian crit. (BIC)	-4219.7	-4428.7

Notes: Sample period: years 2017–2019. Standard errors (in parentheses) are clustered on hospitals. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Conclusions and Policy Implications

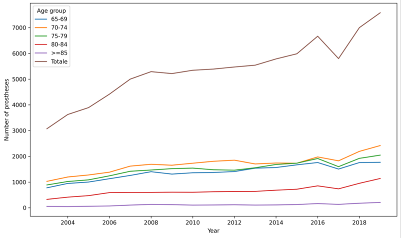
- **Higher** procedural **volumes** are associated with **better outcomes**.
- Results are **consistent** with the **learning-by-doing** dynamic.
- Current **minimum of 75 procedure** per year may **fall short** of fully capturing potential quality gains.
- **Centralisation** may **improve quality** but could **limit access**, adjusting thresholds in line with **local healthcare capacity** and **geographic conditions**.

When Private Providers Serve the Public Health System:

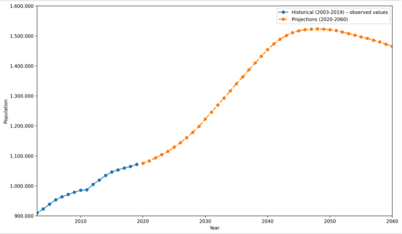
Evidence from an Integrated Healthcare Model

Motivation and Research Question

- **Demand for elective orthopaedic surgery is rising** due to ageing and postponed care (COVID-19).
- Health systems increasingly rely on **accredited private providers**.
- **Evidence on quality differences remains mixed.**
- **Question:** Can private provision expand capacity without compromising **long-term quality**?



(a) Knee procedures by age group



(b) Population projections

Setting & Study design

- **Accredited private hospitals** deliver **publicly funded elective care**.
- **Emilia-Romagna model:** coordinated, planning-based system with strong integration between providers.
- **Study 1 - Survival analysis**
  - Register of Prosthetic Orthopaedic Implants (**RIPO**), 2001–2021.
  - Compare prosthesis survival in public vs accredited private hospitals.
  - Implant failure is defined as **any revision** surgery.
- **Study 2 - Demand forecasting**
  - Use administrative data (SDO) + Eurostat demographic projections.
  - Model and forecast annual volumes of knee arthroplasties in Emilia-Romagna, 2003–2060.
- Together: quality comparison + future demand = framework for **strategic planning** in a highly-integrated system.

Study 1: Survival Analysis

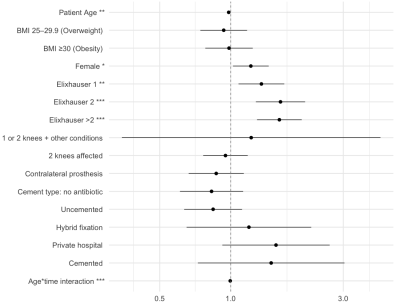
1. **Kaplan–Meier survival curves**
2. **Cox proportional hazards model** with age as a time-varying covariate(stratified by surgeon)

$$h_{s_i}(t) = h_{0s_i}(t) \exp(Z_i\beta + \beta_{\text{age}}\,\text{Age}_i + \gamma_{\text{age}}\,\text{Age}_i \ln(t))$$

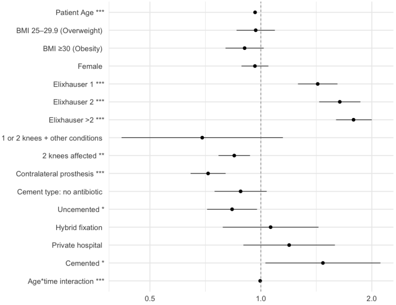
Where:

- s = surgeon
- $h_{0s}(t)$ = surgeon-specific baseline hazard
- Z_i = vector of patient and implant covariates

Study 1: Cox Results



(a) Cox model hazard ratios for UKA, accounting for a time-varying effect of patient age and stratified by surgeon.



(b) Cox model hazard ratios for TKA, accounting for a time-varying effect of patient age and stratified by surgeon.

Study 2: Demand Forecasting

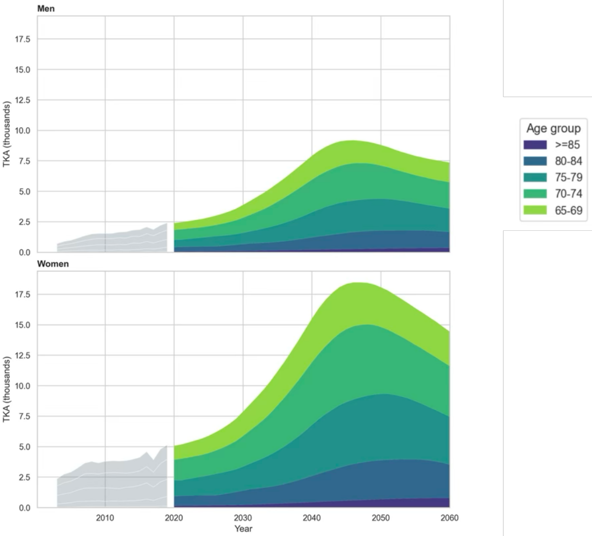
- **Step 1: Count model (NGB1 GLM with log link)**

$$\log(\mu_{it}) = \beta_0 + f(\text{year}) + \text{agegroup}_{it} + \text{sex}_{it} + \log(\text{age65}_{it}) + f(\text{year}) \times \text{agegroup}_{it} + \log(\text{pop}_{it}) \quad (2)$$

- μ_{it}: Expected number of knee replacements in cell i (sex $\times$ age group) in year t.
- $f_k(\text{year}_{it})$: Spline terms capturing a non-linear time trend.
- agegroup_{it}, sex_{it}: Age-group and sex effects.
- $\log(\text{age65}_{it})$: Effect of population ageing (share aged 65+).
- $f_k(\text{year}_{it}) \times \text{agegroup}_{it}$: Interactions allowing different time trends by age group.
- $\log(\text{pop}_{it})$: Offset term controlling for population size.

- **Step 2: Time-series smoothing of residuals**
  - Pearson residuals from the NB model are smoothed using an **ETS process**
  - Final forecast combines **NB predictions** and **ETS residuals**

Study 2: Forecasting Results



Conclusions and Policy Implications

- **No evidence of lower implant survival** in accredited private hospitals after adjustment.
- Knee arthroplasty demand is projected to **grow substantially**, peaking around **2045 (∼27,500 procedures)**.
- Expanding accredited private provision could **increase capacity** and **reduce pressure on public hospitals**.

Hospital Volume and Knee Replacement Outcomes:

Implication for Workforce Participation

Introduction

- **Existing literature** documents a **positive association** between **hospital volume** and **patient outcomes**, but the **causal interpretation** remains unclear due to **endogeneity** (e.g., selective referral vs. learning-by-doing).

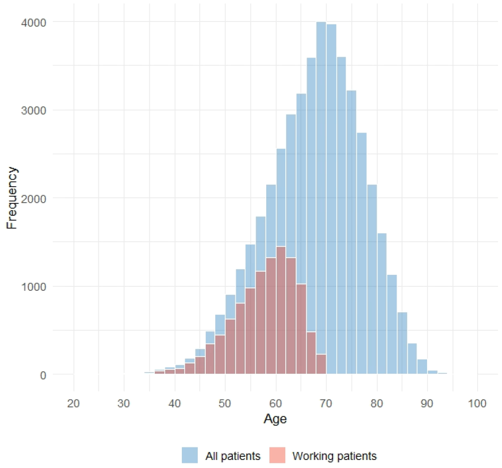
- **Why this setting?**
  - **Elective procedure** $\rightarrow$ strong patient choice
  - **Endogeneity concerns more relevant** than in emergency care
  - Allows analysis of both **clinical** and **labour market outcomes**

- **Research question:** What is the causal effect of **hospital volume** on **clinical** and **labour market outcomes** after primary **knee replacement** in Norway?

Quality indicators

- Two types of **quality indicators**:
  - **Clinical** outcomes:
    - **30-day emergency readmissions**: reflects acute postoperative complications.
    - **revision within 2 years** after **knee replacement** surgery: early implant failure.
  - **Labour market** outcomes:
    - Patient **sick-leave**: Captures **speed of reintegration** into the labour market.
    - **Differential net income**: Reflect ability to sustain employment and earnings.
  - Why labour market outcomes?
    - **Rising procedure rates**.
    - **Return-to-work** as a complementary indicator of surgical success.
    - Employment and income as central to **welfare** $\rightarrow$ **Societal implications**.

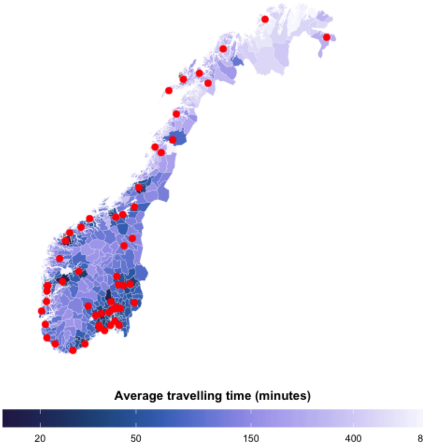
Patient Descriptives



	Total	Working
Mean age	69	58
Mean travel time	88	101
Median travel time	34	38
Chose closest hospital	47%	44%
Charlson 0	92%	95%
Education level:		
Primary & lower secondary school	25%	16%
Technical college	2%	4%
Upper secondary school	49%	49%
Short university	18%	25%
Long university	5%	6%
Clinical outcomes:		
30-day readmissions	11%	–
Revision 2 years	2%	–
Labour outcomes:		
Sick leave (days)	–	157
Salary pre-surg. (NOK)	–	526,707
Salary post-surg. (NOK)	–	467,295
Diff. net income (NOK)	–	-59,411
Diff. median (NOK)	–	-10,950
Manual labour	–	34%
Obs	43,813	10,731

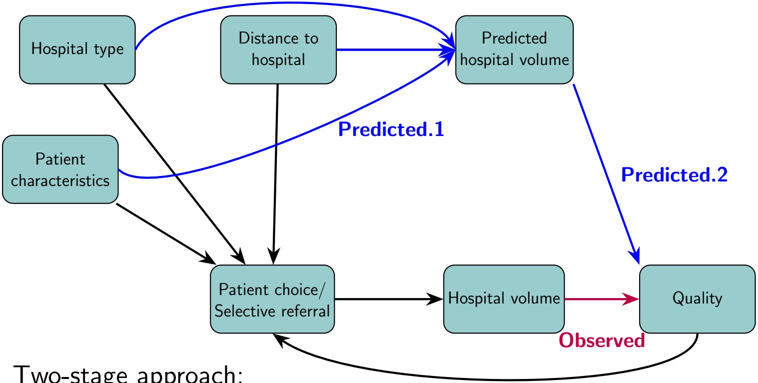
- The exchange rate in 2019 was approximately 10NOK=1EUR

Travel time



- Data: **NPR** and **SSB**.
- Years of analysis: 2012-2019.
- **Travel time distance**:
  Distance matrix linking each **patient's municipality** to all **hospitals** in the dataset.
- Adapted code from Asheim (2021) using **Statens vegvesen's routing** system.
- Used their **Routing API** to calculate realistic travel times on the road network.

Methodology



- Two-stage approach:
  - **First stage**: obtain **predicted hospital volume** using a **conditional logit model** of hospital choice.
  - **Second stage**: pooled OLS regression of outcomes on observed and predicted hospital volume.

First stage

- **Conditional logit** model to analyse patient choice of hospital
- Where V_{iht} is the utility of patient i derived from hospital characteristics h at time t:

$$V_{iht} = \gamma_1 d_{iht} + \gamma_2 d_{iht}^2 + \gamma_3 d_{iht}^3 + \gamma_4 \text{close}_{iht} + z'_{ht}\gamma_z + \sum_{k=1}^{K} x_{ikt}(\gamma_{1k} d_{iht} + \gamma_{2k} d_{iht}^2 + \gamma_{3k} d_{iht}^3)$$

- d_{iht} represents the **distance** (in terms of **minutes**) between patient i (home municipality administrative center) and hospital h (postcode) at time t.
- **Quadratic** and **cubic** terms of distance to allow for a non-linear effect.
- $close_{iht}$, to capture the utility of avoiding any excess travel past the closest hospital.
- z_{ht}: dummy variables for hospital characteristics (i.e. university hospital, private hospital, public hospital) at time t.

First stage

- We can then calculate the predicted volume of hospital h equal to the sum of the estimated probabilities $\hat{p}_{iht}$ across all patients of choosing hospital h:

$$\hat{\text{vol}}_{ht} = \sum_{i=1}^{N} \hat{p}_{iht} = \sum_{i=1}^{N} \frac{\exp(\hat{V}_{iht})}{\sum_{h' \in M_{it}} \exp(\hat{V}_{iht'})}$$

- The conditional logit model is **estimated separately** for **each year** to account for **changes** in the **set of active hospitals** over time.
- This approach allows **patients' hospital choice preferences to vary by year** instead of assuming constant preference parameters.
- **Predicted hospital volume** is constructed from first-stage conditional logit models and defined as the sum of predicted volumes for clinical and labour market populations.

Second stage

- Baseline model is a **pooled OLS**:

$$y_{iht} = \beta_0 + \beta_1 \hat{\text{Volume}}_{ht} + X'_{iht}\beta_2 + \gamma_t + \epsilon_{iht}$$

- $\hat{\text{Volume}}_{ht}$ represents either the actual volume or the predicted volume of knee replacement surgeries in hospital h in year t.
- X'_{iht} patient-level controls (sex, age, number of Charlson comorbidities, patient education level, and — for the labour market outcomes — an indicator for manual occupation).
- γ_t year dummies.
- Where **patient outcomes**:
  - Two labour market: **sick leave duration** and **income change**.
  - Two clinical: **30-day readmission** and **2-year revision surgery**.

Effect of Volume on Clinical Outcomes

30-day readmissions	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00007^{**}		-0.00000	
	(0.00003)		(0.00006)	
Log(volume)		-0.02891^{***}		-0.00154
		(0.00831)		(0.01271)
R^2	0.014	0.016	0.012	0.012
Observations	43,913	43,913	43,913	43,913
Revision within two years	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00001^{**}		0.00002	
	(0.00000)		(0.00002)	
Log(volume)		-0.00204		0.00358
		(0.00179)		(0.00347)
R^2	0.003	0.003	0.003	0.003
Observations	43,913	43,913	43,913	43,913

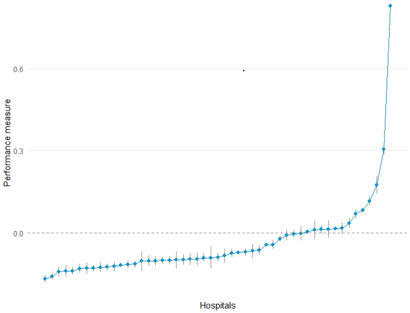
Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Effect of Volume on Labour Outcomes

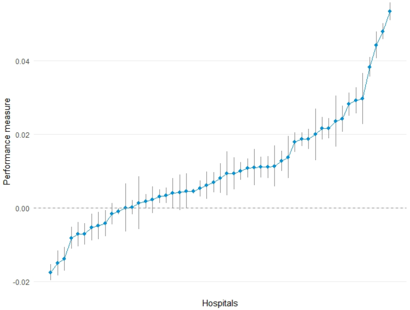
Sick leave	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	0.008		−0.014	
	(0.006)		(0.024)	
Log(volume)		1.686		−2.971
		(2.164)		(4.603)
R^2	0.062	0.062	0.062	0.062
Observations	10,731	10,731	10,731	10,731
Differential net income	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	14.97^{***}		16.70	
	(5.14)		(27.51)	
Log(volume)		$5,264.21^{**}$		$1,018.92$
		(2,092.2)		(5,206.72)
R^2	0.031	0.031	0.030	0.030
Observations	10,731	10,731	10,731	10,731

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Variation in Clinical Outcome Quality Indicators

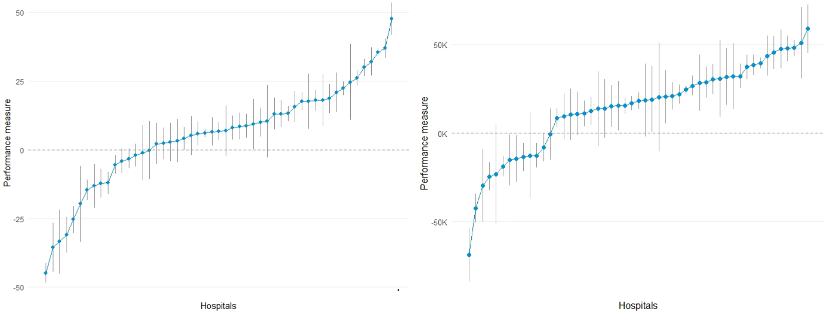


(a) 30-day emergency readmission



(b) Revision within two years

Variation in Labour Market Quality Indicators



(a) Patient sick leave (b) Differential net income

Conclusions & Policy implications

- When accounting for reverse causality using **predicted hospital volume** we find **no** effect on quality.
- Since volume **does not** improve outcomes:
  - We **cannot support centralization** of elective procedures like knee replacements.
  - We should still support policies to **increase** patient access to high-quality, **high-volume** hospitals.
- Attention should shift to **other drivers** of hospital performance: **surgeon-level experience**, **organisational practices**, and **resource allocation**.
- Policies promoting **patient and GP** information on **hospital quality** indicators should be supported.

Thesis Conclusion

- Does organisation shape orthopaedic outcomes? *It depends on the procedure.*

	Hip Fracture (Ch.1)	Knee Arthroplasty (Ch.2)	Knee Arthroplasty (Ch.3)
Setting	Emilia-Romagna	Emilia-Romagna	Norway
Key Finding	Higher volume → lower mortality	Public = Private quality	Volume → no effect on clinical/labour market outcomes
Policy Implication	Centralisation justified	Outsourcing viable	Centralisation not justified

Three Takeaways:

1. **Volume matters — but only for urgent procedures** where experience and coordination are decisive
2. **Outsourcing routine procedures** can relieve public sector pressure without quality loss
3. **Centralisation carries equity costs** only worth bearing when outcome gains are demonstrated

Future research should look beyond hospital volume toward surgeon-level experience and organisational practices as drivers of performance.

Thank you for your attention!

sahar.paktinat2@unibo.it

LinkedIn:

Appendix Menu - Chapter I

Chapter I: Patient summary statistics

Chapter I: Kernel density

Appendix Menu - Chapter II

Chapter II: Patient Characteristics

Chapter II: Knee Replacement Volume

Chapter II: Kaplan-Meier UKA Results

Chapter II: Model Choice

Chapter II: Empirical Strategy Identification

Chapter II: Goodness of fit

Appendix Menu - Chapter III

Chapter III: Second stage model explanation

Chapter III: Effect of volume on 30-day emergency readmission

Chapter III: Effect of volume on patient revision within two years

Chapter III: Effect of volume on sick leave

Chapter III: Effect of volume on differential net income

Chapter III: Robustness Checks

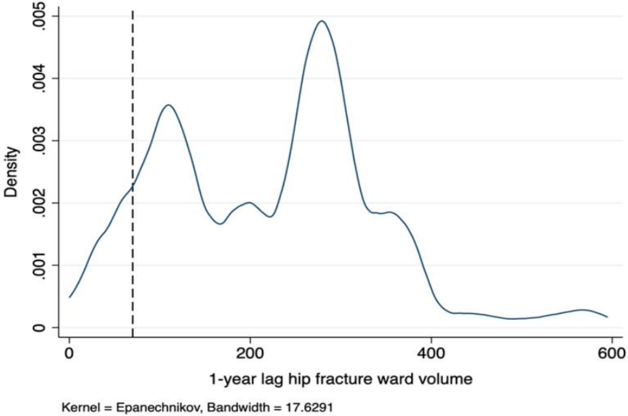
Chapter I: Patient summary statistics

	Mean	Std. Dev.	Min	Max
Patient characteristics				
30-day mortality	0.034	0.183	0	1
Age	83.90	7.437	65	100
Female	0.755	0.430	0	1
Pre-operative wait > 48 hours	0.205	0.404	0	1
Post-surgical length of stay	9.896	6.244	0	175
CCI 0	0.659	0.474	0	1
CCI 1	0.195	0.396	0	1
CCI 2	0.081	0.274	0	1
CCI over 2	0.064	0.245	0	1
ASA I	0.010	0.101	0	1
ASA II	0.233	0.423	0	1
ASA III	0.646	0.478	0	1
ASA IV	0.109	0.312	0	1
ASA V	0.001	0.034	0	1
Admission during weekend	0.272	0.445	0	1
Operation during weekend	0.124	0.330	0	1
Type of surgery				
Partial or total hip replacement	0.497	0.500	0	1
Fracture reduction	0.502	0.500	0	1
Type of hip fracture				
Pertrochanteric	0.438	0.496	0	1
Transcervical	0.535	0.499	0	1
Other type of fracture	0.027	0.163	0	1
Observations	10,377			
Ward volumes for hip fracture surgeries				
Surgeries in the past 4 weeks	17.825	0.325	0	60
Surgeries in the past 12 weeks	53.149	28.985	0	158
Surgeries in the past 24 weeks	105.260	56.369	0	298
Surgeries in the past 52 weeks	224.453	116.918	0	595

Notes: Sample period: years 2017–2019. ASA: American Society of Anesthesiologists.

Back to Appendix Menu

Chapter I: Kernel density



Back to Appendix Menu

Chapter II: Patient Characteristics

Table 2.2: Patient and procedure characteristics of all primary total knee arthroplasties (TKA) and unicompartmental knee arthroplasties (UKA), by type of hospital, years 2001–2021.

Variable	TKA			UKA		
	Private $n = 38{,}676$ Mean SD	Public $n = 31{,}355$ Mean SD	Diff t-stat (95% CI)	Private $n = 5{,}233$ Mean SD	Public $n = 3{,}602$ Mean SD	Diff t-stat (95% CI)
Age < 60	.087 (.281)	.068 (.252)	-.019 (-.023 to -.015)***	.221 (.415)	.160 (.367)	-.061 (-.078 to -.044)***
Age 60–74	.534 (.499)	.532 (.499)	-.002 (-.009 to .005)	.572 (.495)	.603 (.489)	.031 (.010 to .052)***
Age ≥ 75	.379 (.485)	.400 (.490)	.021 (.013 to .028)***	.206 (.404)	.236 (.425)	.030 (.013 to .048)***
Female sex	.714 (.452)	.693 (.461)	-.021 (-.027 to -.014)***	.643 (.479)	.679 (.467)	.036 (.015 to .056)***
Fixation						
Cemented	.951 (.215)	.937 (.242)	-.013 (-.017 to .010)	.929 (.255)	.954 (.209)	-.024 (-.014 to .034)***
Cementless	.038 (.193)	.038 (.192)	.000 (-.002 to .003)	.048 (.214)	.041 (.201)	-.006 (-.015 to .002)**
Hybrid	.009 (.097)	.021 (.146)	.011 (.009 to .013)***	.017 (.050)	.032 (.131)	-.015 (-.019 to .010)***
BMI category						
BMI < 18.5	.002 (.047)	.002 (.041)	-.000 (-.001 to .000)*	.001 (.031)	.002 (.044)	-.006 (-.000 to .002)
BMI 18.5–25	.137 (.344)	.153 (.360)	.015 (.010 to .021)***	.171 (.377)	.164 (.370)	-.007 (-.023 to .009)
BMI 25–30	.356 (.480)	.389 (.488)	.033 (.026 to .040)***	.385 (.486)	.423 (.494)	.038 (.017 to .059)***
BMI ≥ 30	.504 (.499)	.456 (.498)	-.048 (-.056 to -.041)***	.442 (.496)	.410 (.492)	-.032 (-.053 to -.010)***
Elixhauser indices						
Elixhauser 0	.316 (.002)	.216 (.002)	-.100 (-.107 to -.094)***	.427 (.007)	.288 (.007)	-.139 (-.160 to -.119)***
Elixhauser 1	.194 (.396)	.190 (.392)	-.004 (-.010 to .002)	.218 (.006)	.221 (.007)	.002 (-.015 to .019)
Elixhauser 2	.151 (.001)	.162 (.002)	.011 (.005 to .016)***	.135 (.005)	.168 (.006)	.033 (.018 to .048)***
Elixhauser >2	.338 (.002)	.432 (.003)	.093 (.086 to .100)***	.218 (.006)	.323 (.008)	.104 (.086 to .123)***

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter II: Knee Replacement Volume

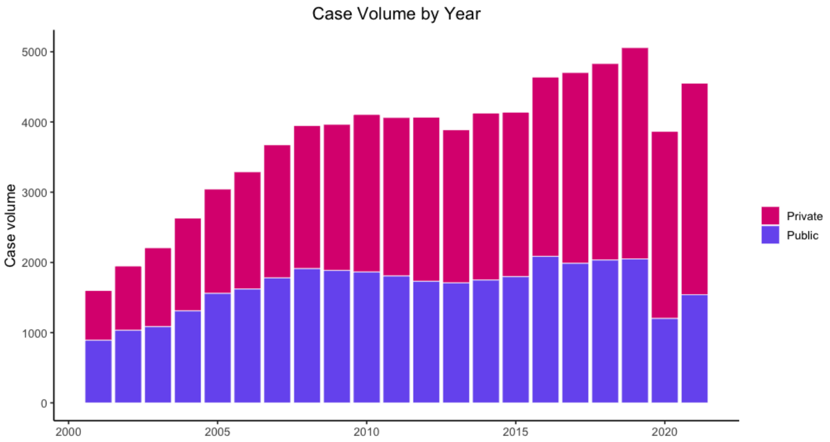
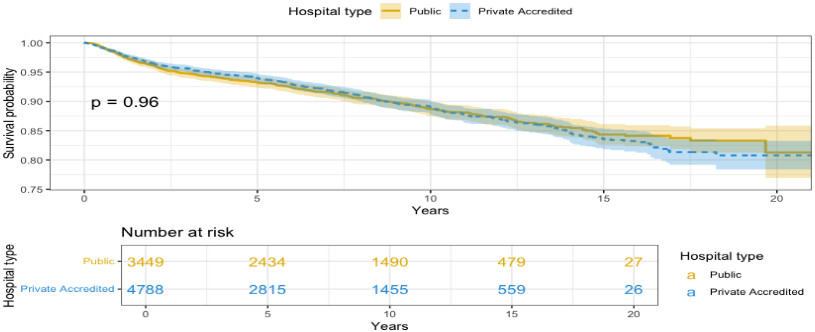


Figure 5: Annual case volume by sector, showing public and private contributions to total cases over time.

Back to Appendix Menu

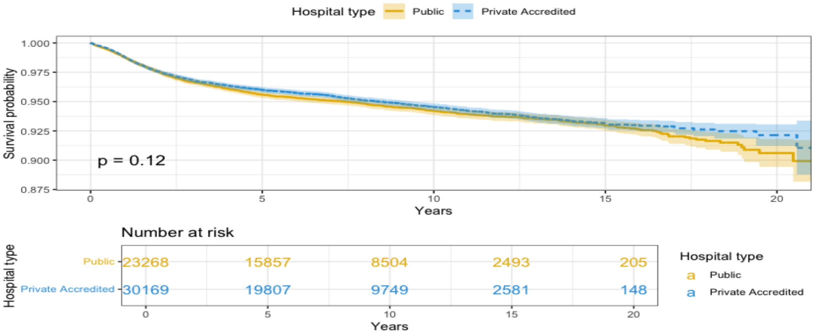
Chapter II: Kaplan-Meier UKA Results



Group	0 Years	5 Years	7 Years	10 Years	15 Years	20 Years
Public	100%	93.2%	91.6%	88.7%	84.3%	81.3%
Private Accredited	100%	93.9%	92%	88.9%	83.6%	80.8%

Back to Appendix Menu

Chapter II: Kaplan-Meier TKA Results



Group	0 Years	5 Years	7 Years	10 Years	15 Years	20 Years
Public	100%	95.6%	95.1%	94.2%	93%	90.6%
Private Accredited	100%	96%	95.5%	94.5%	93.1%	92.1%

Back to Appendix Menu

Chapter II: Model choice

- Model choice: NB1 preferred to NB2 (lower AICc, better Pearson dispersion).
- Fixed holdout (2017–2019):
  - NB1 baseline: MAPE 22.8%
  - NB1 + ETS: MAPE 10.0%

Table 1: Goodness of fit comparisons on predictive accuracy.

Model	**Validation Period**	**MAPE (%)**
NB1 (baseline)	2017–2019	22.77
NB1 + ETS (selected)	2017–2019	10.03
Log-linear (Romanini et al.)	2017–2019	100.00

- **MAPE** = mean absolute percentage error

Back to Appendix Menu

Chapter II: Model choice

3. MAPE comparison across three validation windows

Table 2: Robustness on different holdouts.

Window	MAPE NB1 (%)	MAPE NB1 + ETS (%)
2014–2016	19.7	18.7
2015–2017	21.1	18.4
2016–2018	24.8	23.4

- NB1 + ETS consistently outperforms NB1 alone.

Back to Appendix Menu

Chapter II: Empirical Strategy Identification

- **NB1** specification provides the best goodness of fit to our historical data.

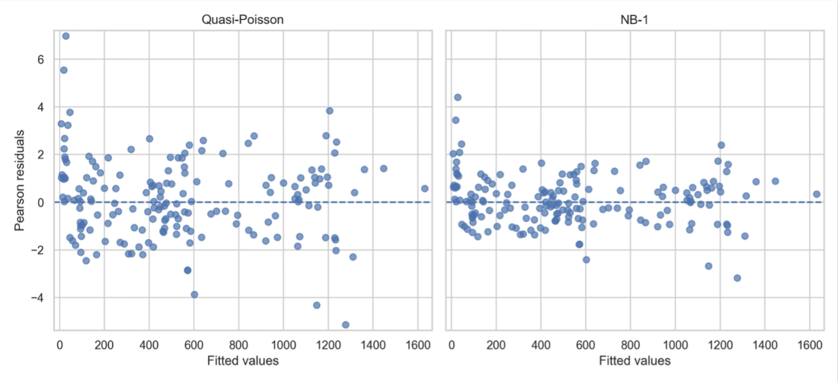


Figure 6: Fitted values vs Pearson residuals.

Back to Appendix Menu

Chapter II: Empirical Strategy Identification

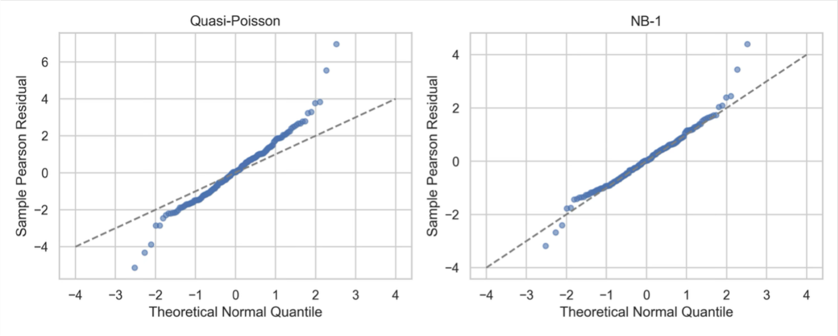


Figure 7: Q-Q plots.

Back to Appendix Menu

Chapter II: Goodness of fit

Table 3: Goodness of fit comparisons of the Negative Binomial Models.

Model	α	Pearson	AICc
NB1	1.5829	1.25	1687.6
NB2	0.00026	1.78	1723.8

Back to Appendix Menu

Second stage model explanation

- **Predicted hospital volume** is constructed from first-stage conditional logit models and defined as the sum of predicted volumes for clinical and labour market populations.

$$\hat{\text{Volume}}_{ht} = \hat{\text{Volume}}_{ht}^{\text{CL}} + \hat{\text{Volume}}_{ht}^{\text{LM}}$$

- Where **patient outcomes**:
  - Two labour market: **sick leave duration** and **income change**.
  - Two clinical: **30-day readmission** and **2-year revision surgery**.
- Second-stage regressions are run separately by outcome and relevant population.

Back to Appendix Menu

Effect of volume on 30-day emergency readmission

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00007^{**}		-0.00000	
	(0.00003)		(0.00006)	
Log(volume)		-0.02891^{***}		-0.00154
		(0.00831)		(0.01271)
R^2	0.014	0.016	0.012	0.012
Observations	43,913	43,913	43,913	43,913
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00005		-0.00007	
	(0.00004)		(0.00008)	
Log(volume)		-0.02414^{**}		-0.03682^{*}
		(0.01023)		(0.01985)
R^2	0.041	0.042	0.041	0.041
Observations	43,913	43,913	43,913	43,913

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Effect of volume on patient revision within two years

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00001^{**}		0.00002	
	(0.00000)		(0.00002)	
Log(volume)		-0.00204		0.00358
		(0.00179)		(0.00347)
R^2	0.003	0.003	0.003	0.003
Observations	43,913	43,913	43,913	43,913
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00000		0.00003^{*}	
	(0.00001)		(0.00002)	
Log(volume)		-0.00093		0.01121^{**}
		(0.00286)		(0.00513)
R^2	0.009	0.009	0.009	0.009
Observations	43,913	43,913	43,913	43,913

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Effect of Volume on sick leave

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	0.008		−0.014	
	(0.006)		(0.024)	
Log(volume)		1.686		−2.971
		(2.164)		(4.603)
R^2	0.062	0.062	0.062	0.062
Observations	10,731	10,731	10,731	10,731
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	−0.015		−0.001	
	(0.014)		(0.033)	
Log(volume)		−0.724		3.549
		(3.468)		(9.041)
R^2	0.075	0.075	0.075	0.075
Observations	10,731	10,731	10,731	10,731

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Effect of volume on differential net income

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	14.97***		16.70	
	(5.14)		(27.51)	
Log(volume)		5,264.21**		1,018.92
		(2,092.2)		(5,206.72)
R^2	0.031	0.031	0.030	0.030
Observations	10,731	10,731	10,731	10,731
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	26.51		59.17	
	(28.74)		(81.28)	
Log(volume)		5,913.26		10,152.32
		(7,703.62)		(19,906.81)
R^2	0.033	0.033	0.033	0.033
Observations	10,731	10,731	10,731	10,731

Notes: In parentheses, robust standard errors are clustered at the hospital level. All monetary values are expressed in NOK. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Robustness Checks - 30-day emergency readmission

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00012^{**}		0.00000	
	(0.00055)		(0.00009)	
Log(volume)		-0.02929^{***}		-0.01187
		(0.00853)		(0.012698)
R^2	0.014	0.016	0.011	0.012
Observations	43,913	43,913	43,913	43,913
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.000085		-0.00011	
	(0.00007)		(0.00013)	
Log(volume)		-0.02547^{***}		-0.03500^{*}
		(0.01015)		(0.01934)
R^2	0.041	0.042	0.040	0.040
Observations	43,913	43,913	43,913	43,913

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Robustness Checks - two-year revision

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00002^{**}		0.000026	
	(0.00006)		(0.000028)	
Log(volume)		-0.00223		0.00323
		(0.00179)		(0.00334)
R^2	0.003	0.003	0.003	0.003
Observations	43,913	43,913	43,913	43,913
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	-0.00001		0.00005^{**}	
	(0.00002)		(0.00003)	
Log(volume)		-0.00107		0.01127^{**}
		(0.00298)		(0.00495)
R^2	0.009	0.009	0.009	0.010
Observations	43,913	43,913	43,913	43,913

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Robustness Checks - Sick leave

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	0.025		−0.034	
	(0.016)		(0.0651)	
Log(volume)		1.877		−2.645
		(2.209)		(4.611)
R^2	0.062	0.062	0.062	0.062
Observations	10,731	10,731	10,731	10,731
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	−0.043		−0.004	
	(0.040)		(0.093)	
Log(volume)		−1.329		1.809
		(3.442)		(8.271)
R^2	0.075	0.075	0.075	0.075
Observations	10,731	10,731	10,731	10,731

Notes: In parentheses, robust standard errors are clustered at the hospital level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu

Robustness Checks - Differential net income

Panel A: Pooled OLS	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	44.52**		55.44	
	(13.70)		(74.39)	
Log(volume)		5,660.73**		2,070.02
		(1,996.38)		(5,280.31)
R^2	0.028	0.028	0.028	0.028
Observations	10,731	10,731	10,731	10,731
Panel B: Inclusion of Hospital FE	Observed hospital volumes		Predicted hospital volumes	
	(1)	(2)	(3)	(4)
Continuous volume	49.78		104.26	
	(78.72)		(223.41)	
Log(volume)		4,855.85		5,415.32
		(7,457.85)		(19,294.66)
R^2	0.031	0.031	0.029	0.029
Observations	10,731	10,731	10,731	10,731

Notes: In parentheses, robust standard errors are clustered at the hospital level. All monetary values are expressed in NOK. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Back to Appendix Menu