Clause and Effect: Public Procurement of Innovation during the First Industrial Revolution

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Full Paper

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What, When and How?

What: Investigate the causal impact of an early form of State procurement of patented inventions

When: British patent system, 1794-1824—height of 'revolution'

How: Exploit a unique quasi-experimental shock to patent administration, applying econometric methods to British patent applications

An historical form of PPI - the Navy Clause Proviso

- Modern innovation studies conceptualise Public Procurement of Innovation (PPI) as a fundamental demand-side tool Georghiou (2007); Edquist and Hommen (2000); Aschhoff and Sofka (2009); Link and Scott (2010); Castelnovo et al., (2018); Gross and Sampat (2023)
  - "Purchasing activities carried out by public agencies that may lead to, or promote, innovation of some kind" Guerzoni and Raiteri (2015)

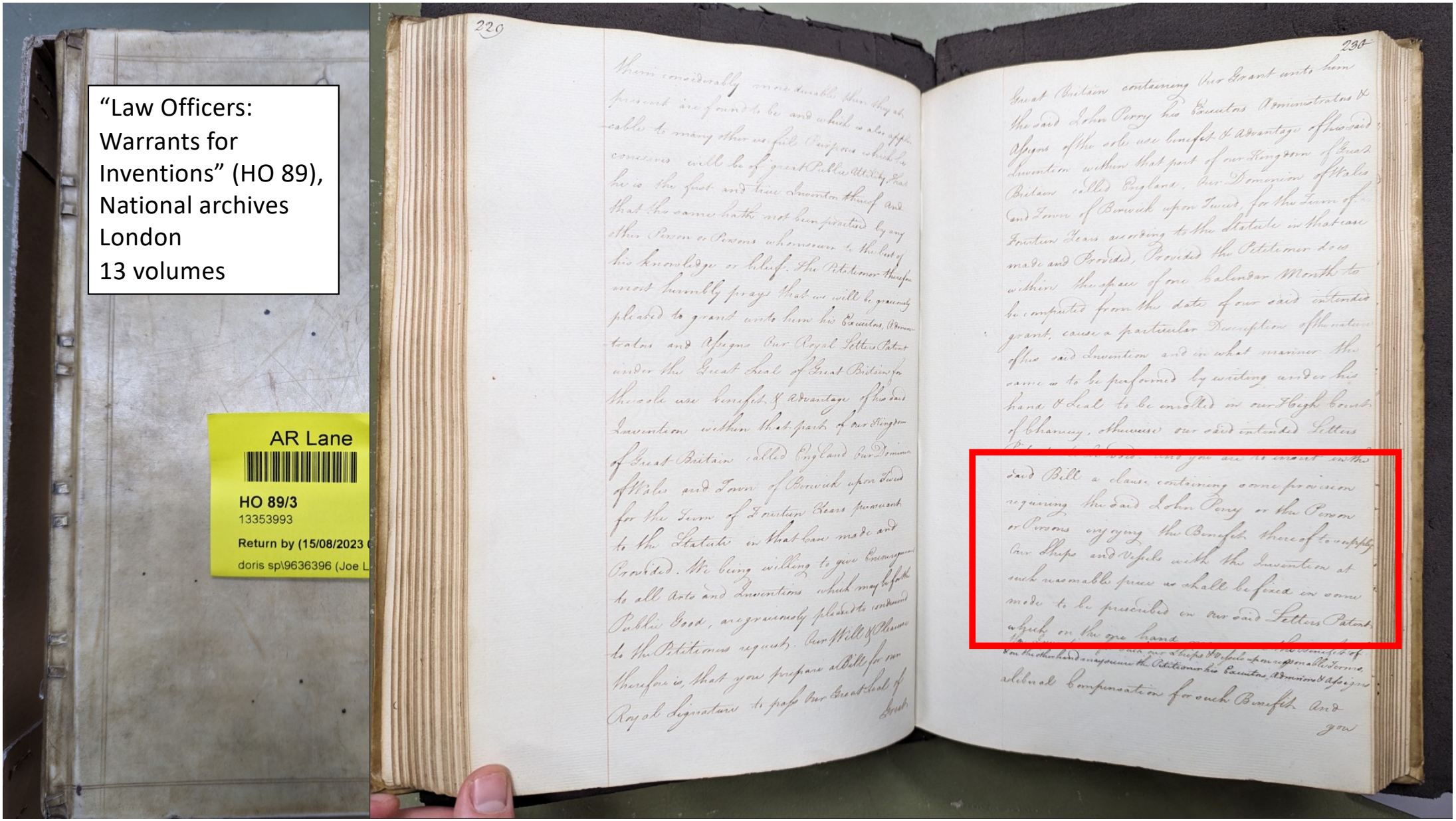
- We identify an early form of procurement targeted at innovation through the British patent system:
  - A public authority purchases access to innovations not yet available on the open market, risk-shares with suppliers through price-premiums
  - Analytical advantages: no tendering process or bargaining; no confounding supply-side mechanisms; long-run patent data

The Navy Clause Proviso

First noted in Bottomley (2014), investigated and conceptualised in Billington & Lane (2026a)

The historical episode of PPI is known as the 'Navy Clause Proviso':

> "[…] and you are to insert in the said Bill a clause containing some provision requiring the said William Fitzgerald […] to supply Our Ships and Vessels with the invention at such reasonable prices as shall be fixed in some mode to be prescribed in our said Letters Patent which on the one hand may secure the benefit of the invention for such our ships and vessels upon reasonable terms, and the other may secure to the […] a liberal compensation for such benefit."
>
> -- Patent warrant record for *William Fitzgerald*, 5th April 1794, for an invention of a bilge pump (Billington and Lane, 2026a: pp.82-3)

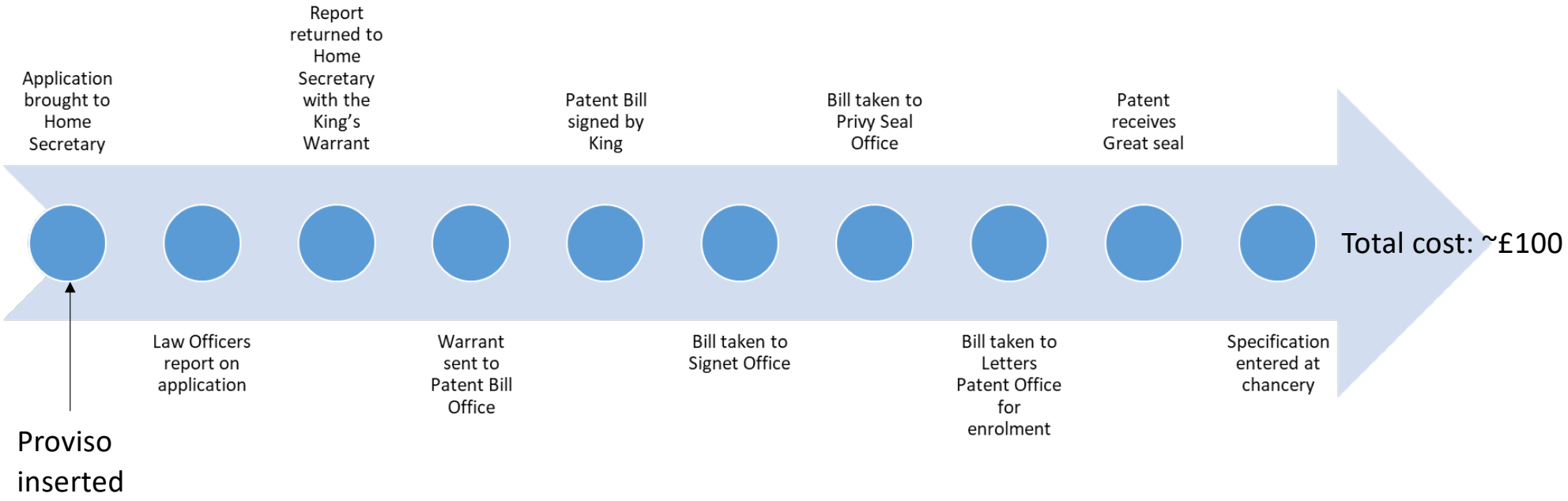


"Law Officers: Warrants for Inventions" (HO 89), National archives London
13 volumes

What was the Navy Clause Proviso?

- The proviso was inserted by the State after receiving a patent application
  - It was at their discretion to identify which innovations they were targeting
  - Failure to adhere to the proviso would void the patent right, and possibly trigger any debt obligations
  - The State offers a general set of terms to the patentee: a short-term price premium for a fixed supply, and a recognizance secured by debt to ensure compliance
- The main benefit to the State is access to new technology to support the war effort
  - Patentee gets IP protection in exchange for a State contract
  - State also sends a market signal that they want new technologies

Britain's Patent System



Core Question

- Did the State's use of the Navy proviso promote innovative activity?
- How did the usage of the Navy proviso affect patenting outcomes for treated patentees?

- We specifically examine whether the proviso influenced observables at the treated patent level, and the treated patentee level

Data

- We examine patent-level and patentee-level data from 1794 to 1824
  - At the patent-level, we restrict each patent to one row in our data
  - At the patentee-level, we include all named patentees as individual rows
- Of the 3,460 patents granted in our window, 413 had a Navy Clause and 3,047 did not

	Patent-level	Patentee-level
First-Treated	301	328
Never-Treated	2,586	2,359

- To measure long-run effects, we observe outcomes for patentees in our sample up to 1850
- Control group those who never received proviso

Methods

- Following PPI literature, we adopt propensity score matching
  - Identify a matched control group, statistically identical to the treatment group based on pre-treatment covariates
- We match on variables which influence both selection into treatment and post-treatment outcomes (Caliendo and Kopeinig, 2008)
- We replicate the information available to the State when assigning the proviso:
  - Occupations; prior patenting history; patent technology; reported savings benefits in patent titles; time dummies; nationality; location; patent title novelty

PSM model

We estimate the propensity score as:

$$p(X_i) = \Pr(D_i = 1|X_i)$$

This is conventionally estimated using a logit model:

$$\hat{p}(X_i) = \frac{\exp\left(X_i'\hat{\beta}\right)}{1 + \exp\left(X_i'\hat{\beta}\right)}$$

Using the propensity score, we can then identify a statistically identical control group by choosing control units that are similar to treated units

- We adopt a 0.25*Std. Dev. Caliper to ensure close matches
- We report nearest neighbour matching with 3 neighbours and replacement

Assumptions: linear in covariates; can be modelled using logit

Isolating the effect

- Overcoming hidden treatment bias:
  - Modern PPI difficult to parse out as firms often receive supply-side R&D grants etc. English patent system isolates the demand-side effect - direct public support for invention was limited
- Reconstructing the decision:
  - Because treatment was assigned unilaterally by the State, we reconstruct the bibliographic information available to the State at the time of the assignment (e.g. occupations, technological domain, prior patenting experience)
- Creating comparators:
  - Using propensity score matching, we pair each NC recipient with observably similar never-treated patentees
- The Measurement:
  - By tracking these matched pairs over the next 5, 10 and 20 years we isolate how receiving a public contract changed an inventor's subsequent trajectory

Estimation model

We are interested in estimating the Average Treatment Effect on the Treated (ATT):

$$\text{ATT} = \mathbb{E}[\, Y_{1i} - Y_{0i} \,|D_i = 1]$$

Let:

$D_i = 1$ if observation i is treated, and $= 0$ if not

$Y_i =$ the outcome of observation i

If we have matched on all relevant confounders then our estimates should be unbiased estimates of the ATT

Definitions of key variables

Variable	Definition
Additional Applications	Total number of future applications filed by each patentee, measured at each patent application We measure up to 5-,10, and 20-years into the future, and the patentee's entire career.
Average WSI Scores of future patents	The average number of Woodcroft-Subject Matter Index (WSI) classes assigned per additional application (from Billington and Lane, 2026a)
Future-saving	The total count of future patents which claim, in either the title or specification, to save on: labour, or capital, or both (based on Macleod, 1998; Billington, 2021)
Forward Similarity	Inverse cosine similarity measure between each patent and the population of future patent specifications, measured up to 1-,5-,10-,20-, and 30-years into the future.
Backward Similarity	Inverse cosine similarity measure between each patent specification and the population of prior patent specifications filed up to 5-years previously.
Breakthrough Scores	The ratio of a patent's total forward similarity relative to its backward similarity score (defined by Kelly et al., 2023)
Absolute BCI	The absolute value of a patent's Bibliographic Composite Index estimate (Nuvolari et al., 2021)
Adjusted WRI	A time-weighted value indicating the number of references received by a patent in the contemporary scientific and trade literature (Nuvolari and Tartari, 2011)

Core Findings

- Persistent increase in quantity:
  - Treated inventors filed more patents over 5-, 10- and 20-year horizons
- Market Mechanism:
  - Most pronounced effect was directional - State successfully signalled a willingness to pay for cost-saving technologies, and inventors reallocated their efforts toward labour- and capital-saving inventions
- Incremental not radical:
  - Little evidence that treatment increased economic value, contemporary visibility, or radicality of patented inventions.
- Procurement shifted the direction of patenting toward cost-saving trajectories rather than transforming the technological frontier

Headline results (NN1:3)

Variable	Unmatched Estimate	Matched Estimate
Patent Quality		
Number of References (WRI)	-0.0827** (0.0336)	-0.0251 (0.0433)
Economic Value (BCI)	-0.0075 (0.0140)	-0.0228 (0.0230)
Quality of Future Patents		
Avg. Number of References (WRI)	-0.0046 (0.0182)	-0.0238 (0.0248)
Avg. Economic Value (BCI)	-0.0124 (0.0120)	-0.0049 (0.0200)
Avg. Technological Scope (WSI)	0.0519** (0.0237)	0.0476 (0.0337)
Reporting of Cost-savings in Future Patents		
Labour-saving	0.0189** (0.0094)	0.0211** (0.0093)
Capital-saving	0.0344 (0.0240)	0.0632** (0.0246)
All savings	0.0447* (0.0248)	0.0736*** (0.0253)
Total Future Patents		
After 5yrs	-0.0213 (0.0352)	0.1052** (0.0425)
After 10yrs	-0.0106 (0.0424)	0.1116* (0.0594)
After 20yrs	0.0093 (0.0490)	0.1522** (0.0685)
All-time	0.0203 (0.0511)	0.1553** (0.0711)

Headline results (NN1:3)

Variable	Unmatched Estimate	Matched Estimate
Similarity		
Forward Similarity (5 yrs)	-0.0107* (0.0058)	-0.0233*** (0.0082)
Forward Similarity (30 yrs)	-0.0084 (0.0051)	-0.0214*** (0.0076)
Novelty and Influence of Future patents		
Avg. Backward Similarity (5yrs)	0.0056 (0.0079)	0.0084 (0.0102)
Avg. Forward Similarity (5yrs)	0.0060 (0.0075)	0.0091 (0.0098)
Avg. Forward Similarity (30yrs)	0.0056 (0.0062)	0.0083 (0.0107)
Breakthrough Scores		
Breakthrough (5-5)	-0.0196 (0.0191)	-0.0041 (0.0257)
Breakthrough (30-5)	-1.3873*** (0.3916)	-0.4594 (0.4021)
Breakthrough Scores of Future patents		
Avg. Breakthrough (5-5)	0.0145 (0.0357)	0.0378 (0.0440)
Avg. Breakthrough (30-5)	-1.9909*** (0.7510)	-1.4606 (1.5583)

Methodological robustness checks

King & Neilson (2019) critique of PSM – not appropriate for matching

- **Alternative:** Covariate-balance propensity scores
  - Instead of matching only on PS distance, CBPS attempts to incorporate balance on covariates

Model misspecification might also be a problem if true relationship is non-linear nor appropriately represented using a logit model

- **Alternatives:** Inverse probability weighting, Entropy Balancing, Doubly Robust
  - IPW uses all observations and applies PS-based weightings; EB forces balance on covariates; DR combines PS-weighting with outcome regression

	MATCHING (PSM)	MATCHING (CBPS)	WEIGHTING			NON-PARAMETRIC		
OUTCOME	NN 1:3	CBPS 1:3	IPW	EB	DR	NP-KR	NP-IPW	NP-DR
SIMILARITY & BREAKTHROUGH								
Forward similarity (5 yr)	−0.0233***	−0.0239***	−0.0204*	−0.0281***	−0.0280***	−0.0285*	−0.0238***	−0.0263***
	(0.0082)	(0.0081)	(0.0106)	(0.0098)	(0.0084)	(0.0132)	(0.0069)	(0.0074)
Forward similarity (30 yr)	−0.0214***	−0.0221***	−0.0188*	−0.0244***	−0.0244***	−0.0277**	−0.0204***	−0.0232***
	(0.0076)	(0.0075)	(0.0100)	(0.0091)	(0.0073)	(0.0115)	(0.0062)	(0.0065)
Avg. Breakthrough (5-5)	+0.0378	+0.0370	+0.0582	+0.0616*	+0.0972**	+0.1278	+0.0440	+0.0926*
	(0.0440)	(0.0441)	(0.0374)	(0.0371)	(0.0454)	(0.0967)	(0.0381)	(0.0534)
PATENT QUALITY								
Avg. Technological Scope	+0.0476	0.0491	+0.0552*	+0.0591*	+0.0412	+0.0369	+0.0554*	+0.0421
	(0.0337)	(0.0333)	(0.0286)	(0.0334)	(0.0296)	(0.5830)	(0.0286)	(0.0296)
COST-SAVING FUTURE PATENTS								
Labour-saving	+0.0211**	+0.0211**	+0.0219**	+0.0222**	+0.0222**	+0.0225**	+0.0220**	+0.0219**
	(0.0093)	(0.0093)	(0.0095)	(0.0096)	(0.0092)	(0.0088)	(0.0094)	(0.0097)
Capital-saving	+0.632**	+0.0632**	+0.0631**	+0.0666**	+0.0665***	+0.0604	+0.0547**	+0.0550**
	(0.0246)	(0.0246)	(0.0250)	(0.0259)	(0.0241)	(0.0383)	(0.0250)	(0.0221)
Any saving	+0.0736***	+0.0736***	+0.0750***	+0.0784***	+0.0783***	+0.0724*	+0.0663**	+0.0672***
	(0.0253)	(0.0253)	(0.0256)	(0.0266)	(0.0246)	(0.0388)	(0.0257)	(0.0229)
FUTURE PATENTING ACTIVITY								
Applications (5 yr)	+0.1052**	+0.1069**	+0.0768*	+0.0877**	+0.0878**	+0.0712	+0.0619	+0.0709*
	(0.0425)	(0.0421)	(0.0392)	(0.0420)	(0.0350)	(0.0657)	(0.0381)	(0.0365)
Applications (20 yr)	+0.1522**	+0.1546**	+0.1335**	+0.1308*	+0.1308**	+0.1268	+0.1071*	+0.1026*
	(0.0685)	(0.0681)	(0.0607)	(0.0671)	(0.0583)	(0.1195)	(0.0565)	(0.0541)
Applications (all time)	+0.1553**	+0.1577**	+0.1454**	+0.1358**	+0.1358**	+0.1373	+0.1096*	+0.1027*
	(0.0711)	(0.0707)	(0.0627)	(0.0681)	(0.0582)	(0.1206)	(0.0565)	(0.0549)

Core Findings

- Did the proviso have a positive impact on patenting activity at the patent or patentee-level?
  - Yes, we find an increase in patents sought in treatment group over short and long-run

- Did the proviso influence the trajectory of innovation?
  - Treatment likely caused an increase in the reporting of labour- and capital-saving benefits; some evidence that treatment led to patents of broader technological scope

Check #1: Political or military connections

- Selection into treatment likely influenced by network connections, and those connections might influence future patenting trajectories
- Cannot directly control for networks, but proxy for them using occupational-based ‘status’ variables:
- Political connections: we code occupations which report and ‘noble’ title as a dummy
  - E.g., lord, earl, knight, duke, baron, viscount
- Military connections: officers in the military arguably had better connections as well, we code a ‘military naval officer’ dummy:
  - E.g., admiral, capital, lieutenant, major
- Caveat: variables might influence selection into treatment only

Check #2: Exposure to the Navy

- Another important confounder is whether proviso recipients were either in private correspondence with Navy personnel, or able to identify relevant technological needs
  - This would influence selection into treatment, but might also influence innovation outcomes if inventors can leverage this private information for commercial effect
- Our approach: construct proximity measures between a patentee's reported town and the Royal and private dockyards, using tonnage production metrics as a weight
  - We draw on shipbuilding metrics produced by Knight (2003) who reports dockyards (private and Royal) which built at least 10 ships during the Napoleonic wars

Interpretation: channels and mechanisms

- **A "Market-Size Mechanism" (Directed Technical Change):**
  - The Navy Clause acted as a demand-side market-size intervention.
  - Public demand did not produce radical frontier breakthroughs, but it steered innovation toward labour- and capital-saving trajectories.
- **Twin Channels of Persistence:**
  - Commercialisation Channel: Guaranteed demand and price premiums relaxed financial constraints, providing the capital needed to fund expensive future patent applications.
  - Signalling Channel: Unilateral procurement credibly revealed State priorities, reducing market uncertainty for inventors targeting cost-saving solutions.
- **The Patent System as a Screening Device:**
  - Heavy upfront fees (~£100) ensured that inventors only patented inventions they believed had genuine commercial value. This allowed the State to identify viable technologies without needing modern technical evaluation committees or complex tenders.

Interpretation: channels and mechanisms

- **Disclosure and Cumulative Invention:**
  - Whether procurement induced brand-new inventions or incentivised inventors to choose patenting over trade secrecy, the outcome was the same: greater public codification and diffusion of technical knowledge.
- **Understanding Similarity Scores:**
  - Lower forward similarity indicates that the State was not procuring general-purpose civilian technologies, but rather niche, speculative, or military-specific solutions.

Conclusion

- PPI instruments influence invention activities through providing grounds for successful commercialisation of risky technologies
- Our findings link to First Industrial Revolution
  - increase in cost-saving technologies means either invention was fostered, or, at the very least, the patenting of such inventions was encouraged (diffusion effects)
  - State willingness to bear considerable risk likely helped encourage activities related to the Industrial Revolution
  - Labour-saving tech famously associated with the Industrial Revolution
- Raises the question of whether modern PPI instruments are crucial to direct ongoing 4IR (a question not yet asked)

Thanks for listening

Full Paper

Check #1: Results

Variable	Main Model	Model with Political Connections
Patent Quality		
Number of References (WRI)	-0.0251 (0.0433)	0.0151 (0.0385)
Economic Value (BCI)	-0.0228 (0.0230)	-0.0178 (0.0243)
Quality of Future Patents		
Avg. Number of References (WRI)	-0.0238 (0.0248)	-0.0223 (0.0261)
Avg. Economic Value (BCI)	-0.0049 (0.0200)	-0.0097 (0.0269)
Avg. Technological Scope (WSI)	0.0476 (0.0337)	0.0679* (0.0365)
Reporting of Cost-savings in Future Patents		
Labour-saving	0.0211** (0.0093)	0.0091 (0.0181)
Capital-saving	0.0632** (0.0246)	0.0674** (0.0272)
All savings	0.0736*** (0.0253)	0.0798*** (0.0277)
Total Future Patents		
After 5yrs	0.1052** (0.0425)	0.1165*** (0.0402)
After 10yrs	0.1116* (0.0594)	0.0968 (0.0676)
After 20yrs	0.1522** (0.0685)	0.1506* (0.0769)
All-time	0.1553** (0.0711)	0.1583** (0.0783)

Check #2: Tonnage metrics

Dockyard	Type	No. of Ships	Tonnage	Average Tonnage
Frindsbury (Medway)	Private	23	16177	703
Hull	Private	11	9971	906
Topsham	Private	26	8862	341
Ipswich	Private	23	7556	329
Bucklers Hard	Private	10	7438	744
Dartmouth	Private	17	6592	388
Dover	Private	16	5314	332
Bridport	Private	18	5168	287
Lynn	Private	13	4203	323
Newcastle	Private	13	3722	286
Yarmouth (Isle of Wight)	Private	15	3386	226
Deptford/Woolwich	Royal	39	41608	1067
Chatham/Sheerness	Royal	16	20594	1287
Portsmouth	Royal	14	12800	914
Plymouth	Royal	7	12807	1830
Pembroke	Royal	6	7151	1192

Check #2: Estimating proximity

- We construct measures of patentee 'accessibility' to dockyards:
  - Raw distance – straight-line km distance to the nearest dockyard of each type
  - Tonnage-weighted accessibility – gravity model index summing inverse distance to each dockyard, weighted by shipbuilding output; converted into standardised z-scores:

$$\text{Accessibility}_{\text{i}} = \sum_{j=1}^{n} \frac{W_j}{\max(D_{ij}, 1)}$$

- Distance is measured by geolocating towns and dockyards using OpenStreetMap (tidygeocoder package in R)
  - First pass resulted in 94 geocoding failures – a result of incorrect spellings
  - Manual correction resulted in successful geocoding of over 99% of towns

Check #2: Estimating proximity

- We recently identified a dataset of individual ships built across the eighteenth and nineteenth century at various English dockyards
  - These report year built, guns on ship, and the dockyard
  - No tonnage reported
  - Source: Age of Nelson
- We use this as a second proxy for distance to important dockyards, constructing a similarity accessibility index but weighting by: ships built or guns on ships built by dockyard by year
  - Likely suffers a similar measurement problem as Knight's data
  - Unclear if this is a representative sample or suffers a degree of survivorship bias

Check #2: Results

Variable	Main Model	Model with Tonnage	Model with Ships	Model with Guns
Patent Quality				
Number of References (WRI)	-0.0251 (0.0433)	0.0001 (0.0457)	-0.0165 (0.0462)	0.0025 (0.0453)
Economic Value (BCI)	-0.0228 (0.0230)	-0.0154 (0.0229)	-0.0127 (0.0264)	-0.0078 (0.0264)
Quality of Future Patents				
Avg. Number of References (WRI)	-0.0238 (0.0248)	-0.0235 (0.0222)	-0.0255 (0.0222)	-0.0137 (0.0223)
Avg. Economic Value (BCI)	-0.0049 (0.0200)	-0.0089 (0.0159)	-0.0166 (0.0252)	-0.0126 (0.0180)
Avg. Technological Scope (WSI)	0.0476 (0.0337)	0.0540 (0.0328)	0.0524 (0.0350)	0.0519 (0.0358)
Reporting of Cost-savings in Future Patents				
Labour-saving	0.0211** (0.0093)	0.0247*** (0.0088)	0.0225** (0.0090)	0.0260*** (0.0087)
Capital-saving	0.0632** (0.0246)	0.0557* (0.0313)	0.0657** (0.0308)	0.0596* (0.0321)
All savings	0.0736*** (0.0253)	0.0675** (0.0317)	0.0767** (0.0313)	0.0720** (0.0326)
Total Future Patents				
After 5yrs	0.1052** (0.0425)	0.0714 (0.0549)	0.0681 (0.0545)	0.0449 (0.0566)
After 10yrs	0.1116* (0.0594)	0.0847 (0.0727)	0.0697 (0.0748)	0.0561 (0.0768)
After 20yrs	0.1522** (0.0685)	0.1232 (0.0849)	0.1129 (0.0861)	0.1038 (0.0885)
All-time	0.1553** (0.0711)	0.1287 (0.0865)	0.1283 (0.0871)	0.1135 (0.0897)