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Scaling robotic surgery in the NHS: National expenditure projections and adaptive budget-impact scenarios for soft-tissue platforms

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Abstract

Background: Robot-assisted soft-tissue surgery is expanding in the NHS. Policymakers need estimates of the public cash required to scale access, both in gross terms and net after accouting for existing laparoscopy costs.

Methods: We built ten-year, England-wide, payer-perspective budget-impact models using 2023/24 surgical activity. Multiple platforms were simulated and grouped by capability and cost (A premium, B mid-tier, C low-cost hybrid). Nine scenarios crossed three adoption targets (30%, 50%, 90% robotic by Year 5) with three deployment mixes (Full A; Mixed A+B; Hybrid A+B for major, C for high-throughput lists). Capital was spread across Years 1-5; replacement was 4%/year in Years 6-10; consumables ramped to steady state by Year 5. The primary analysis was cash total without discounting (national expenditure projection) and a prespecified sensitivity analysis offset existing laparoscopic costs (budget impact scenario), taking into account a 20% open to robotic conversion rate. A pay-per-use (PPU) variant was explored for 90% adoption.

Results: Gross programme spend rose during implementation and then stabilised as replacement dominated. At Year 5, gross spend was 0.03% (30% Hybrid), 0.14% (50% Mixed), and 0.29% (90% Full) of the NHS budget, settling by Year 10 at 0.02%, 0.09%, and 0.18%. In the budget-impact sensitivity model, displaced laparoscopy costs offset 18-45% of the robotic spend depending on scenario, yielding a lower net investment that peaks at Year 5 and settles to 0.02-0.17% of the NHS budget by Year 10. At that point, annual gross versus net spend were £0.05bn vs £0.03bn for 30% Hybrid, £0.33bn vs £0.16bn for 50% Mixed, and £0.93bn vs £0.33bn for 90% Full. PPU smoothed annual outlay at 90% adoption but did not materially change the ten-year totals. If each robotic system achieves a throughput at 350 cases per year, overall programme cost reduce by approximately 8% across scenarios.

Interpretation: Robotic expansion in the NHS appears affordable if utilisation is managed, with existing laparoscopy offsetting a meaningful share of the required spend. Flexible contracting (e.g. subscription based models) can smooth early spending without altering long-run totals. Roll-out should proceed alongside a ten-year programme of clinical outcome research to confirm cost-effectiveness and refine investment over time.

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Introduction

Robot-assisted surgery is expanding rapidly in the NHS. Recent national announcements set an ambition for nine in ten minimally invasive operations to be robot assisted within a decade, with activity projected to increase from 70,000 procedures in 2023/24 to 500,000 a year by 2035[1-4]. In parallel, NICE has introduced an Early Value Assessment approach that enables conditional adoption where there is unmet need but requires explicit evidence generation plans and ongoing review of real-world outcomes[5-7]. Together, these policy signals create a clear imperative to understand the budgetary implications of scaling soft-tissue robotics across the NHS[1-7].

As systems move from pilots to delivery at scale, choices about deployment strategy, service configuration and contracting will determine affordability. Options include applying premium platforms for complex major resections but the cost impact of using lower cost technologies on simple, high-throughput lists is unproven. In parallel, commercial approaches range from capital purchase to subscription based pay-per-use models. Alongside these operational decisions sit wider aims that include maintaining equitable access, protecting training, and generating outcomes evidence during the NICE Early Value Assessment evidence generation window. For NHS policy makers to make decisions going forwards, a clear view of the budgetary implications and drivers of cost are needed for planning and to influence service design[5-8].

We therefore set out to estimate the national budget impact of different options for national robotic expansion in soft-tissue surgery in England. We modelled annual programme spend over ten years under varying adoption targets and deployment mixes, reporting cash totals, shares of the NHS budget, and budgetary impact from offsetting existing laparoscopy spends.

Methods

Study design and perspective

We conducted a national expenditure projection and budget-impact modelling study of soft-tissue robotic surgery for the NHS in England from the payer perspective over a ten-year horizon without discounting, reflecting cash budgeting practice. Reporting was structured to follow relevant domains of the International Society for Pharmacoeconomics and Outcomes Research Budget Impact Analysis good-practice guidance (ISPOR BIA); completed checklists are provided in the Supplement. The objective was to estimate annual programme cash costs and shares of the NHS budget under alternative adoption targets and deployment mixes.

Data sources and baseline caseload

Surgical volumes were drawn from Hospital Episode Statistics (HES) 2023/24 “Primary Procedure, 4-character OPCS-4” tables at Finished Consultant Episode level[9]. Rows were filtered to valid four-character procedure codes and mapped to clinically coherent soft-tissue families spanning abdominal, pelvic, thoracic and selected transoral ENT procedures; orthopaedics was excluded[9]. Minimally invasive surgery (MIS) proportions were assigned at specialty procedural level from national audits and guidance that reflect contemporary NHS practice. Sources included National Bowel Cancer Audit, National Oesophago-Gastric Cancer Audit, National Prostate Cancer Audit and BAUS resources, British Association of Day Surgery cholecystectomy guidance and GIRFT day-case implementation materials, NICE technology or interventional guidance for hernia and oesophagectomy, NHS National Obesity Audit and BOMSS (British Obesity & Metabolic Specialist Society) reports, and peer-reviewed studies on adoption patterns; the numerical fractions used per family and citations are listed in the Supplement[10-21].

Procedure set

The soft-tissue set comprised operations where minimally invasive surgery (MIS) is currently used, including: cholecystectomy, appendicectomy, abdominal wall hernia repair, bariatric procedures, anti-reflux and hiatus hernia surgery, colon resections, rectal resections, oesophagectomy and gastrectomy, liver resections, pancreatic resections, lung resections and thymectomy, radical prostatectomy, radical cystectomy, partial and radical nephrectomy, pyeloplasty, adrenalectomy, hysterectomy, oophorectomy and salpingo-oophorectomy, ectopic pregnancy surgery, small-bowel resections, and defined transoral ENT (ear, nose, throat) or oral resections suitable for TORS (transoral robotic surgery). Endoscopic procedures were excluded. The complete mapping of OPCS-4 descriptions to families is provided in the Supplement[9].

Platform archetypes (Type A/B/C robots)

We modelled three soft-tissue robotic archetypes to represent the range of systems available to the NHS without tying results to specific vendors. Type A was defined as a premium multi-arm platform intended for a full range of complex major resections through to minor surgery, Type B was a mid-tier system suitable for a share of major and intermediate/minor work, and Type C was a lower cost, laparoscopic-hybrid platform used mainly on high-throughput simple lists.

Capital prices, per-case consumables, and annual case capacities were set specified a priori based on industry-derived estimates taken from triangulation of publicly available procurement notices, manufacturer documentation, and expert briefings. Where multiple figures existed, we selected conservative mid-points and documented a plausible range for sensitivity analysis. Final base-case values were capital £1.8m (Type A robot), £1.2m (Type B robot), £0.25m (Type C robot); per-case consumables £2,000 (A), £1,500 (B), £250 (C).

Annual capacities reflect assumed staffed theatre time, turnover, and case mix. We derived per-system throughput from list length, proportion of major versus simple cases, and realistic utilisation after set-up and changeover. These rates are intended to represent steady-state delivery rather than initial ramp-up. Annual steady-state capacities reflected typical list structures: 250 cases/year for A and B, 350 cases/year for C. These values are planning rates rather than mandated targets. Annual robot capacity at maturity was set at 250 cases per year for Types A and B and 350 for Type C, reflecting full-weekday booking and GIRFT guidance on high-volume, multi-session days for simple lists, with higher local throughputs attainable under three-session templates[14, 22, 23].

Scenarios, mixes, and platform parameters

We modelled nine scenarios formed by crossing three adoption targets with three deployment mixes. Adoption targets were 30%, 50%, and 90% of current minimally invasive (MIS) cases delivered robotically by the end of year 5, then held through year. Deployment mixes were defined based on consensus amongst authors and taken as follows: Full used Type-A only; Mixed allocated Types A and B at 60% and 40% across both major and simple lists; Hybrid allocated Types A and B at 60% and 40% for major resections and, for simple lists, Types A, B, and C at 10%, 10%, and 80%. Major versus simple families were predefined so that complex resections remained on A/B while high-throughput simple lists could run on C.

Adoption ramp, replacement and denominators

We modelled adoption as increasing linearly to the scenario target by Year 5 and plateaued thereafter. Rolling replacement at 4% of the active fleet per year was applied in Years 6-10 on a like-for-like basis. The NHS cash budget denominator was set at £192 billion in Year 1 with 2% nominal growth per year for Years 2-10, consistent with published DHSC aggregates used for comparative budgeting[21,22]. Annual outputs were cash totals and percentage shares of the NHS budget.

Model structure, reproducibility and outputs

For each family, we applied the MIS fraction to HES volumes to define the MIS pool. Robotic cases were allocated to platform types according to the scenario mix. Required in-service fleet equalled cases divided by per-platform capacity, rounded up to the next integer. Purchases in each year topped up to requirement; from Year 6 they also included a 4% replacement calculated on the prior on-fleet count, rounded down. Capital outlay equalled purchases times platform prices. Consumables equalled cases times per-case prices. Annual programme cost was the sum.

A large language model (GPT-5 Thinking, OpenAI; execution date 14 September 2025, Europe/London) orchestrated the end-to-end computational workflow, including data retrieval and curation, harmonisation of source mappings to OPCS-4 families, structuring of scenario definitions, model specification, code generation and execution, and production of analytic tables and figures; domain experts provided iterative review and corrective feedback at each stage. All data ingestion, transformations, calculations and figure generation were executed in Python (pandas, numpy) in a scripted environment, so that all numerical outputs were independent of the large language model. Prompts, parameter sheets and script versions are time-stamped and archived to support reproducibility. Figures apply cubic-spline smoothing across Years 1-10 for presentation only. A; ll reported values are discrete yearly outputs produced by the code.

Sensitivity analysis 1: high replacement

We repeated the three headline scenarios (Hybrid 30%, Mixed 50%, Full 90%) but increased rolling fleet replacement from 4% to 20% per year in Years 6-10 (equivalent to a five-year asset life). All other parameters were unchanged: installed base credited as Type A robots as 112 in practice, Type B as 28, and Type C as 0; capacities A 250, B 250, C 350 cases per year; unit prices A £1.8m and £2,000 per case, B £1.2m and £1,500 per case, C £0.25m and £250 per case; linear ramp to the adoption target by Year 5 then held; NHS budget denominator £192bn in Year 1 with 2% nominal growth per annum.

Sensitivity analysis 2: Pay per use

We created a pay-per-use (PPU) sensitivity analysis for the 90% scenarios. The per-case fee equalled instruments/consumables plus a capital-recovery surcharge over seven years at platform capacity (A/B 250, C350 cases/year). Year-10 platform case allocations from the base model were ramped linearly to Year 5 and held flat thereafter; all capital purchases and replacements were removed. Annual programme spend under PPU was cases*fee by platform and year.

Sensitivity analysis 3: laparoscopic offset for budget impact model

To estimate incremental cash impact relative to existing minimally invasive provision, we extended the base budget-impact model with a laparoscopic counterfactual. The annual pool of minimally invasive soft-tissue procedures was fixed at 196,240 cases. Robotic uptake ramped linearly to each scenario's target by Year 5 and remained constant thereafter. Of robotic cases, 80% displaced laparoscopy and 20% were assumed to represent conversions from open surgery. The laparoscopic installed base was sized to cover this pool at 325 cases per stack per year, with consumables of £500 per case, a capital cost of £200,000 per stack, £10,000 annual maintenance, and 10% annual replacement. Two baselines were tested: a **no-credit** baseline that retained laparoscopy replacement and maintenance unchanged, and a **utilisation-adjusted** baseline that reduced these in proportion to the share of minimally invasive surgery displaced by robotics, discounted by 0.8 to reflect open conversions. Robotic parameters and NHS-budget denominators were identical to the main model (capex spread across Years 1-5, 4 % annual replacement in Years 6-10, consumables ramping to steady state by Year 5; NHS budget starting at £192 billion with 2% nominal growth). Incremental outcomes were annual and cumulative additional NHS cash spend, net percentage of the NHS budget, and incremental cost per robotic case.

Sensitivity analysis 4: impact of higher annual case volume (350 cases per system)

A throughput sensitivity analysis tested higher platform utilisation. Annual capacity for platforms A and B was increased from 250 to 350 cases per system, matching the performance of Type C. All other assumptions, including prices, replacement rate (4% per year in Years 6-10), installed base, and adoption ramp, were held constant. Fleet requirements and annual programme costs were recalculated for the 30 % Hybrid, 50 % Mixed, and 90 % Full scenarios.

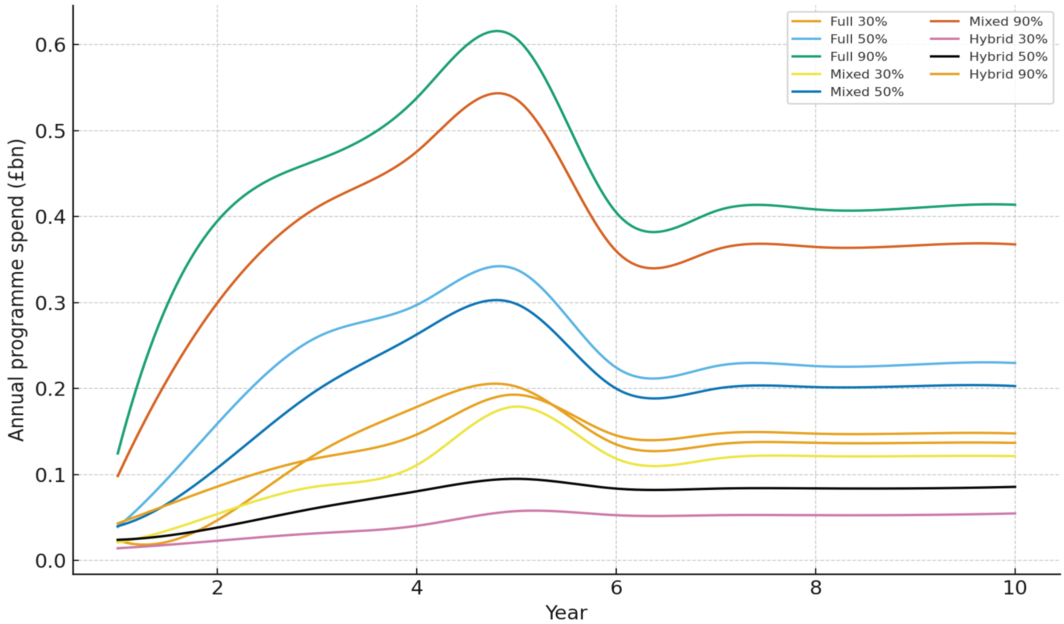
NHS budget comparison

Year-5 robotic programme spending was compared with major NHS spending lines for context. Comparator shares use DHSC group outturn totals for 2023/24, with total departmental expenditure limits of £188.6 billion as the denominator. Robotic scenario shares use the model's NHS cash budget, which starts at £192 billion in Year 1 with 2% nominal growth and is applied at Year 5. Reported comparator and robotic percentages therefore use different denominators and years.

Validation

To validate the model, we independently reconstructed the key calculations in Microsoft Excel using the published inputs: procedure families and MIS proportions from Table S2, adoption targets and platform mixes from Table S3, unit costs, capacities, installed base and budget series from Table S4, and the linear ramp to year 5 (Methods) with 4% annual replacement in years 6-10 from Table S4 (with a 20% replacement sensitivity in Table S6). Families were classified as major or simple as specified. For each scenario, robotic cases were allocated to platforms according to mix weights; required fleets derived from annual capacities (CEILING rule);

Figure 1. Robotic surgery programme cost scenarios for soft tissue tracer conditions, as an annual % of NHS budget



Programme cost as a share of the total NHS budget over ten years for all nine adoption combinations (targets 30/50/90%× mixes Full/Mixed/Hybrid). Curves are spline-smoothed yearly totals; costs rise during the five-year ramp and then level as replacement dominates. The upper envelope (90% Full) peaks at ~0.24% in Year 5 and settles near 0.14% by Year 10; the mid-range (50% Mixed) at ~0.12%→0.07%; the low-cost entry (30% Hybrid) at ~0.018%→0.019%.

Table 1: MIS procedure groups and baseline rates

Family	Total FCE 2023/24	Estimated MIS FCE (family)	Weighted MIS %
Adrenalectomy	950	807	85
Appendicectomy	50,310	45,736	90
Bariatric (sleeve/bypass/band)	2984	2925	98
Cholecystectomy	69,436	65,964	95
Colon resections (colectomy/hemicolectomy)	19,895	13927	70
ENT/oral - transoral resections (TORS subset)	1483	370	25
Ectopic pregnancy surgery (salpingectomy/ salpingostomy)	143	121	85
Fundoplication / Anti-reflux / Hiatus hernia repair	1690	1606	95
Hysterectomy (benign and cancer)	28,339	14,452	51
Inguinal/abdominal wall hernia	99,045	34,668	35
Lung resection (lobectomy/segmentectomy)	7242	2897	40
Oesophagectomy / Gastrectomy (cancer)	979	520	53
Oophorectomy / Salpingo-oophorectomy	1249	999	80
Pancreatic resection (DP/PD/Whipple)	2270	223	10
Pyeloplasty	1224	979	80
Rectal resections	10,816	7572	70
Small bowel resection (jejunum/ileum)	5215	3129	60
Thymectomy	162	81	50

purchases calculated as incremental fleet increases with replacement from Year 6 (FLOOR rule); and annual costs obtained as capital costs (capex) plus consumables.

Results

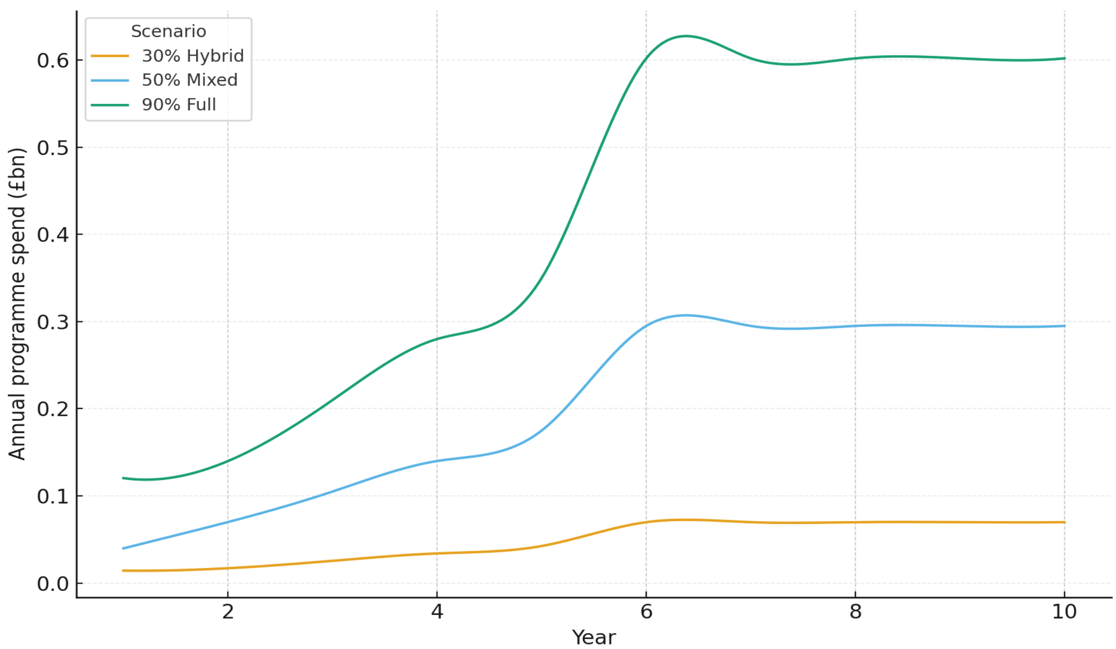
Baseline activity and behaviour across scenarios

The expanded mapping of Hospital Episode Statistics identified 196,240 minimally invasive soft-tissue cases per year. Major families comprised colorectal, oesophagogastric, liver, pancreas, lung, prostate, cystectomy, nephrectomy, and adrenalectomy; simple lists comprised cholecystectomy, appendicectomy, abdominal wall hernia, bariatric procedures, anti-reflux and hiatus hernia surgery, hysterectomy, oophorectomy and ectopic pregnancy, pyeloplasty, and small-bowel resections. Across all nine scenarios, annual costs rose during the linear ramp to year 5 and then flattened as rolling replacement dominated (Figure 1). The baseline pool and minimally invasive fractions are detailed in Table S2.

Headline scenarios at years 5 and 10

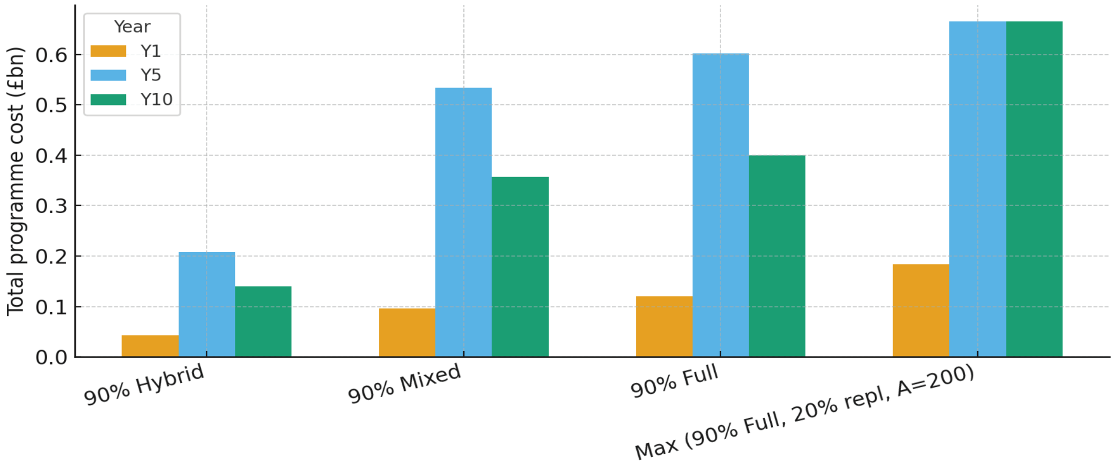
At year 5, programme spend was £0.055 bn (0.0267% of the NHS budget) for 30% Hybrid, £0.297 bn (0.1428%) for 50% Mixed, and £0.602 bn (0.2896%) for 90% Full (Figure 1). By year 10, the corresponding figures stabilised at £0.054 bn (0.0235%), £0.201bn (0.0878%), and £0.409bn (0.1781%). Year-10 national fleet sizes were A133/B39/C137 for 30% Hybrid; A282/B187 for 50% Mixed; and A850/B33 for 90% Full (Figure 4). Capital outlays were front-loaded: in years 1-5 they were £36.0m, £373.2m, and £1,058.4m for 30% Hybrid, 50% Mixed, and 90% Full, with replacement capex of £49.3 m, £123.6m, and £276.0m across years 6-10; steady-state year-10 consumables were £42.5m, £175.0m, and £350.0m, respectively. These quantities and annual trajectories are reported in Table S5; underlying unit prices, capacities, installed base and the 4% replacement rule are summarised in Table S4.

Figure 2: Sensitivity to 20% annual fleet replacement (Years 6-10)



Three scenario curves show annual programme spend (£bn) over ten years under a five-year replacement cadence. Curves are spline-smoothed across Years 1-10; replacement begins in Year 6, lifting the tail for all scenarios. The effect scales with the proportion of Type-A/B platforms: largest for Full 90%, intermediate for Mixed 50%, and least for Hybrid 30%, which relies on lower-cost Type-C for simple lists. Year-5 peaks are identical to the base model because replacement has not started. NHS budget denominator is £192bn in Year 1 with 2% nominal growth. Unit prices, capacities, installed base, and adoption ramps are as in the main Methods.

Figure 3: Annual spend for 90% scenarios and a maximum sensitvitiy analysis at years 1, 5, 10



90% Hybrid, 90% Mixed, 90% Full are from the base model with 4% annual replacement in Years 6-10; "Max" is 90% Full with 20% annual replacement in Years 6-10 and Type-A capacity set to 200 cases/year; all other parameters unchanged; Prices, capacities, installed base, NHS budget series, MIS pool and mapping/exclusions are as per the supplement you signed off.

Ordering and drivers

The scenario spread showed consistent ordering by both adoption target and deployment mix. Within a given target, Hybrid had the lowest cash envelope because simple lists were allocated to lower unit-cost technology while preserving A/B capacity for complex resections; Mixed lay between Hybrid and Full; Full had the highest capex and consumables. Within a given mix, higher adoption increased cases, consumables, and required fleet in a monotonic fashion. The five-year ramp produced peaks at year 5 as activity reached maturity, after which consumables dominated and rolling replacement set the tail. These patterns appeared in both percentage-of-budget and cash-terms views because the same NHS budget denominator series was applied across scenarios. Scenario definitions and mix weights are listed in Table S3. Cumulative non-staff spend across the

Table 2: model parameters and key outputs for the three highlighted cost models

	30% Hybrid	50% Mixed	90% Full
Baseline MIS cases (per yr)	196,240	196,240	196,240
Robotic cases at steady state (per yr)	58,872	98,120	176,616
On-fleet Yr10 A	133	284	858
On-fleet Yr10 B	40	189	33
On-fleet Yr10 C	137	0.0	0.0
New robots purchased over 10y A	21	172	746
New robots purchased over 10y B	12	161	5
New robots purchased over 10y C	137	0	0
Capex Y1-Y5 (£m)	37	378	1071
Replacement capex Y6-Y10 (£m)	49	125	278
Consumables at steady state (£m/yr)	44	177	353
Programme cost % NHS budget Y1	0.008	0.021	0.065
Programme cost % NHS budget Y5	0.028	0.144	0.292
Programme cost % NHS budget Y10	0.024	0.088	0.18
Total programme spend 10y (£bn)	0.43	1.92	4.17
10y share of NHS budget (%)	0.021	0.091	0.199

30% Hybrid: low-cost entry with Type-C lap-hybrid dominating simple lists (A/B retained for major cases); 50% Mixed: mid-range deployment using an A/B blend across major and simple procedures; 90% Full: upper-bound A-only fleet replacing most MIS activity across pathways.

Table 3: Year 5 robotic programme spending in context of major NHS spending lines

Item	Year	Spend (£bn)	Share of NHS budget (%)	Source
`Provider staff costs	2023/24	85.1	45.1	Consolidated NHS Provider Accounts 2023/24
Medicines (hospital + community)	2023/24	21.68	11.5	Provider accounts + NHSBSA PCA 2023/24
Community prescriptions (NIC)	2023/24	10.9	5.78	NHSBSA Prescription Cost Analysis 2023/24
Hospital medicines (providers)	2023/24	10.78	5.72	Consolidated NHS Provider Accounts 2023/24
Clinical supplies (providers)	2023/24	9.0	4.77	Consolidated NHS Provider Accounts 2023/24
Premises (providers)	2023/24	5.15	2.73	Consolidated NHS Provider Accounts 2023/24
90% Full robotic scenario (upper bound, Year 5)	Year 5 (model)	0.607	0.292	Our model (Year-5)
Cancer Drugs Fund (CDF)	2023/24	0.34	0.180	NHS England finance papers 2023/24
Innovative Medicines Fund (IMF)	2023/24	0.34	0.180	Parliamentary written answer (allocation)
50% Mixed robotic scenario (mid-range, Year 5)	Year 5 (model)	0.298	0.144	Our model (Year-5)
NHS Blood and Transplant	2023/24	0.128	0.068	NHSBT Annual Report & Accounts 2023/24
Care Quality Commission (net expenditure)	2023/24	0.061	0.032	CQC Annual Report & Accounts 2023/24
NICE (net expenditure)	2023/24	0.058	0.031	NICE AR&A 2024/25 (prior-year figure)
30% Hybrid robotic scenario (low-cost entry, Year 5)	Year 5 (model)	0.058	0.028	Our model (Year-5)

Items ranked by share of NHS budget. Comparator percentages use DHSC group outturn totals for 2023/24 (TDEL ~£188.6bn). Robotics figures are Year-5 model outputs (cash terms and %). The 30% Hybrid scenario represents a low-cost entry; the 50% Mixed scenario a mid-range view; and the 90% Full scenario an upper-bound envelope at maturity. "Share of NHS budget" for robotics uses your model's Year-5 percentages. Percentages for external comparators use DHSC group outturn totals for 2023/24 as the NHS budget proxy (see supplement).

ten-year horizon followed the same rank ordering, with steeper early accrual in higher-adoption and premium mixes (Figure 5; Table S5).

Sensitivity analyses

Assumptions about asset life and utilisation materially affected the tail. Increasing rolling replacement from 4% to 20% per year in years 6-10 (a five-year asset life) raised year-10 spend for the three headline scenarios while leaving year-5 peaks unchanged; the absolute effect was largest for 90% Full, intermediate for 50% Mixed, and smallest for 30% Hybrid, reflecting each mix's exposure to premium platforms (Figure 2; Table S6). In a separate stress test focused on expensive mixes, combining five-year replacement with reduced throughput for Type-A further increased steady-state shares and long-run spend, with the largest absolute effect at 90% Full (Figure 3; Table S5).

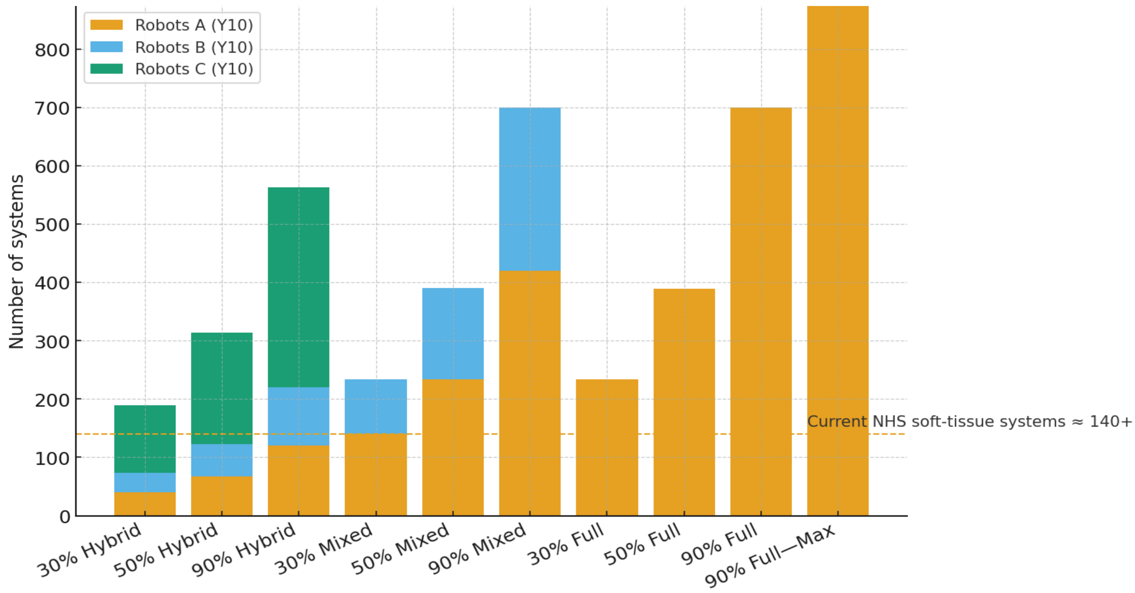
Pay-per-use sensitivity

Applied to the 90% scenarios as a budgeting sensitivity, pay-per-use preserved the base-case ordering and produced smooth annual profiles that reached a plateau by year 5, consistent with capital recovery embedded in per-case fees. The principal effect was to re-profile cash while leaving overall envelopes similar under like-for-like assumptions (Figures S-PPU-1/2; Supplement section "PPU sensitivity (90% scenarios), methods and results"; associated tables in the same section).

Laparoscopy offset sensitivity

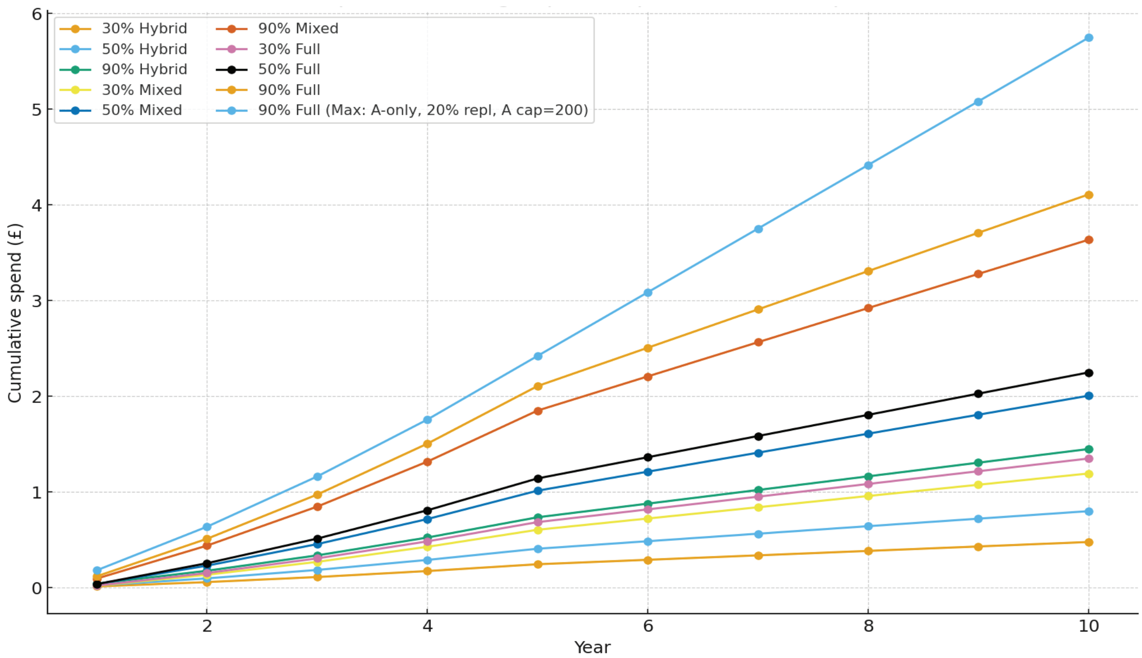
Crediting displaced laparoscopy reduced the robotic envelope materially but did not erase the need for new cash. On a utilisation-adjusted basis, offsets covered about 45% of robotic spend at 30% Hybrid, 29% at 50% Mixed, and 19% at 90% Full by Year 5, settling near 42%, 20%, and 19% by Year 10, respectively. Over ten years, cumulative offsets accounted for roughly 43%, 22%, and

Figure 4: Robotic systems required by scenario (Y10): NHS soft-tissue surgery



Stacked bars show the mix of platforms needed by Year 10 under each scenario. "A" = single-platform Full model; "B" = additional platform in Mixed/Hybrid; "C" = third platform in Hybrid only. Scenarios reflect adoption levels (30/50/90%) across three families: Full (A only), Mixed (A+B), and Hybrid (A+B+C). The 90% Full-Max label is a stress test with A only, higher demand, and separate replacement/cap rules in the paper. Dashed line marks the current NHS soft-tissue baseline (~140 systems).

Figure 5: Cumulative non-staff spend on NHS soft-tissue robotic surgery (capital + per-case, 10-year rollout & replacements)



One line per scenario: 30/50/90% Hybrid (A+B+C), 30/50/90% Mixed (A+B), 30/50/90% Full (A only), and "Full-Max" stress test (A only, 20% replacement from Year 6, A capacity=200). Spend includes capital for new installs and replacements plus per-case consumables; it excludes staff costs, maintenance/service, estates/financing and discounting. Rollout is linear to Year 5 then held at Year-10 volumes. Installed base credited at start: A=112, B=28, C=0. Replacement rate 4% per year in Years 6-10 for all scenarios except "Full-Max" at 20%. System capacities (cases/year): A=250 (200 in Max), B=250, C=350. Unit prices: A £1.8m, B £1.2m, C £0.25m. Per-case costs: A £2,000, B £1,500, C £250. Figures shown in nominal £ with no inflation adjustment.

16% of total robotic spend across the same scenarios, so the NHS still faced a modest net increase concentrated in the roll-out phase. By Year 10 the annual gross versus net new spend was approximately £0.054 bn vs £0.03

Table 4: Scenario steady-state fleet and annual cases at Year 10

Scenario	Robots A (Y10)	Robots B (Y10)	Robots C (Y10)	Cases A (Y10)	Cases B (Y10)	Cases C (Y10)
30% Hybrid	40	34	115	9990	8327	40,011
50% Hybrid	67	56	191	16,650	13,879	66,685
90% Hybrid	120	100	343	29,970	24,981	120,033
30% Mixed	140	94	0	34,997	23,331	0.0
50% Mixed	234	156	0	58,328	38,885	0.0
90% Mixed	420	280	0	104,990	69,994	0.0
30% Full	234	0	0	58,328	0.0	0.0
50% Full	389	0	0	97,213	0.0	0.0
90% Full	700	0	0	174,984	0.0	0.0
90% Full (Max: A-only, 20% repl, A cap=200)	875	0	0	174,984	0.0	0.0

Robots are the required in-service fleet at Year 10 (after the Year-5 ramp); replacement purchases do not change fleet size. "Cases" are Year-10 annual robotic cases allocated to each platform. Baseline caseloads are from HES 2023-24 with the documented appendicectomy override to 45,000 MIS cases. Mixes: Full (A-only); Mixed (A 60% / B 40% for all lists); Hybrid (Major A 60% / B 40%; Simple A 10% / B 10% / C 80%). The "Max" row is a stress-test with A-only, five-year replacement (20%/yr in Years 6-10) and A capacity 200 cases/year.

Table 5. Offsets created by displacing laparoscopy.

Scenario	Year 5 offset (£bn)	Year 5 offset (% of robotic spend)	Year 10 offset (£bn)	Year 10 offset (% of robotic spend)	10-year cumulative offset (£bn)	10-year offset (%of robotic spend)
30% Hybrid	0.028	54.3%	0.028	51.9%	0.223	51.0%
50% Mixed	0.046	18.4%	0.046	23.0%	0.372	19.4%
90% Full	0.084	14.8%	0.084	20.5%	0.670	16.0%

bn (30% Hybrid), £0.334 bn vs £0.16 bn (50% Mixed), and £0.931 bn vs £0.33 bn (90% Full), translating to a net share of the NHS budget of about 0.02–0.17% across scenarios. The apparently small movement in NHS-budget percentages reflects the much larger denominator: the offsets are a sizeable fraction of robotic spend, but the net effect on the whole NHS budget is correspondingly modest (Figure 6 and Table 5).

Higher volume sensitivity analysis

Raising throughput from 250 to 350 cases per system reduced fleet sizes by about 30 % and lowered capital spending by 7–9 % across all scenarios, while consumable costs remained unchanged. The overall ten-year programme cost fell proportionally, with budget shares and incremental cost per case decreasing in similar magnitude.

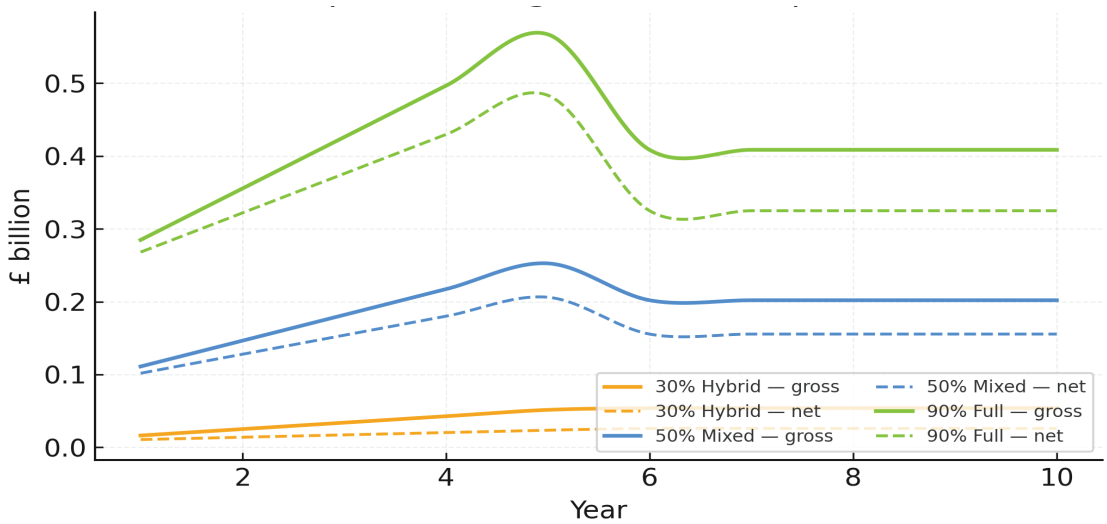
NHS Budgetary implications

Placing year-5 programme spend against major NHS lines indicated that 90% Full sits above an individual ring-fenced medicines fund; 50% Mixed lies between those funds and selected arm's-length body budgets; and 30% Hybrid is near the scale of a single regulator's net expenditure. Comparator percentages are anchored to 2023/24 DHSC outturn, whereas programme percentages use the model's year-5 cash denominator; these figures are indicators of scale rather than like-for-like shares, and a harmonised restatement does not alter the qualitative ordering (Table S7).

Validation

We independently reconstructed the key calculations in Microsoft Excel using the published inputs, procedure families and minimally invasive fractions from Table S2; scenario adoption targets and platform mixes from Table S3; unit prices, capacities, installed base, NHS budget series, and the 4% replacement rule from Table S4; and the linear ramp to year 5 as specified in Methods (with the 20% replacement sensitivity in Table S6). For each scenario, robotic cases were allocated to platforms according to mix weights; required fleets were derived

Figure 6: Annual NHS budget impact for robotic surgery across adoption scenarios.



Solid lines show gross programme spend; dashed lines show net new investment after accounting for displaced laparoscopic costs (utilisation-adjusted baseline). All scenarios exhibit substantial offsets, reducing but not eliminating the budget impact.

Table 6. Sensitivity analysis of increased platform throughput (350 cases per system): effect on fleet size and programme cost

Scenario	Year-5 spend (£ bn)	Δ vs base	Year-10 spend (£ bn)	Δ vs base	Ten-year total (£ bn)	Δ vs base
30 % Hybrid	0.050	−9 %	0.049	−9 %	0.44	−8 %
50 % Mixed	0.275	−7 %	0.186	−7 %	1.87	−7 %
90 % Full	0.560	−7 %	0.380	−7 %	3.83	−7 %

from annual capacities using a ceiling rule; purchases combined top-up to requirement and, from year 6, rolling replacement (floor rule); and annual costs were the sum of capital outlays and per-case consumables. Across the three headline scenarios (30% Hybrid, 50% Mixed, 90% Full), year-5 programme spend matched the manuscript waypoints within £5-10 million of £0.055 bn, £0.297 bn, and £0.602 bn, respectively. Early discrepancies were resolved by applying the predefined major/simple classification and the 80% routing of simple cases to Type C in the Hybrid mix. Overall, the results are reproducible from the stated assumptions and equations (Tables S2-S6).

Discussion

This national budget-impact analysis indicates that scaling soft-tissue robotic surgery across the NHS is financially manageable across all scenarios, with flexibility when deployment is planned and task-matched. Gross programme costs rise during implementation and then flatten as rolling replacement dominates; when we credit displaced laparoscopy, 18-45% of robotic spend is offset, yielding a smaller net new investment that peaks around Year 5 and settles near 0.02-0.17% of the NHS budget by Year 10, even in high-adoption scenarios. Mixes that reserve premium platforms for complex resections and use lower unit-cost systems for high-throughput lists deliver the lowest cash envelopes at any given adoption target, and the rank ordering is robust to stress tests, reinforcing configuration and utilisation as the primary drivers of affordability. The key interpretation is denominator logic: offsets are a large fraction of the robotic envelope, but a small fraction of the whole NHS budget, so the headline percentage moves only modestly despite sizeable cash savings. Finally, subscription arrangements can smooth five-year outlay by shifting capital into per-case fees without materially changing the ten-year totals, making PPU a financing choice rather than a change in overall affordability. This needs to next be set against clinical outcomes and cost-effectiveness data to fulfil NICE's Early Value Assessment pathway and support local decisions[1-7,23].

Greater platform utilisation substantially improves capital efficiency without altering clinical throughput. At 350 cases per system, total cost and incremental cost per case decline by roughly 8 %, demonstrating the strong sensitivity of programme economics to list productivity. These findings reinforce that operational factors, particularly scheduling and theatre access, are as influential as equipment price in determining real-world value.

Our results sit within and extend the existing literature on minimally invasive adoption and service configuration in the NHS. National audits describe high but heterogeneous MIS use in colorectal cancer and mixed adoption for oesophagogastric resections, while radical prostatectomy is predominantly robotic; daycase cholecystectomy is overwhelmingly laparoscopic[10-13]. Service guidance from GIRFT and NHS England emphasises networked, high-volume programmes, careful case selection, training, and evaluation, which is consistent with the scenario structures modelled here[14,17,18]. By translating these service principles into ten-year cash trajectories, the analysis offers a comparative frame that complements outcome studies and single-centre costings[19,23].

This work has important limitations and should be interpreted with appropriate caution. First, NHS adoption decisions are grounded in cost-effectiveness metrics such as incremental cost-effectiveness ratios, which require linkage between costs and patient outcomes; we did not model outcomes (for example complications, recovery, readmissions, quality of life) and therefore cannot speak to Incremental Cost-Effectiveness Ratios or net health benefit. Second, the model is deliberately top-down, built on national averages and simple replacement rules; hospitals differ markedly in case mix, staffing, theatre efficiency, estates constraints and scheduling, so local business cases may diverge. Third, we assumed planning-rate capacities per robot: doubling Type-A/Type-B throughput from 250 to 500 cases per year lowered spend in illustrative scenarios, but such utilisation is ambitious in some areas and under-ambitious in others. Fourth, the baseline minimally invasive pool was estimated from HES at code-family level with MIS fractions from national audits; these sources mask inter-trust variation, centralisation effects and year-to-year shifts in case mix. Fifth, we did not model patient-level conversions, complications, length of stay, productivity offsets or downstream resource use; any net clinical or operational gains (including reduced length of stay, reinterventions or open conversions) could materially change both budget impact and value. Sixth, replacement, throughput and consumables were implemented as simple rules (a linear ramp to year five, like-for-like replacement thereafter, fixed steady-state capacities and cash per-case consumables, whereas in practice replacement is driven by obsolescence, uptime, service contracts and financing, throughput varies with theatre access and staffing, and consumables depend on tray design, contracting and re-use policy. Seventh, alternative commercial arrangements beyond capital purchase were not comprehensively analysed; while we tested a pay-per-use sensitivity, leases, managed services and hybrid models were not explored in depth and could shift cash profiles for trusts with limited capital. Eighth, capital enabling works, estates constraints and theatre reconfiguration were not included. Ninth, a minor limitation is that we focused on robotic substitution within the MIS pool rather than explicit conversion of open cases to robotic surgery, although in contemporary NHS practice most target procedures are already largely minimally invasive. Finally, a large language model was used to accelerate evidence collation and scenario-book generation. While this improved speed and transparency, parameter choices and mappings require ongoing verification and periodic refresh as audits and guidance update. Overall, the results should be read as a planning envelope rather than a cost-effectiveness verdict, but they provide a clear starting framework that can be adapted with local data, prospective outcomes and trust-specific contracting assumptions[8-19,23].

The offset analysis is important to understand the actual budget impact on the NHS as a whole and at local level. It also has limitations, as it assumes proportional reductions in laparoscopic replacement and maintenance from a fixed MIS pool, applies planning prices for laparoscopic bundles and installed base that may vary locally, excludes staffing, estates, financing and productivity effects, uses undiscounted cash flows, and therefore may under- or over-state net savings if service reconfiguration does not fully release those costs.

The policy implications reflect DHSC's stated ambition and will require deliberate configuration of platforms, rigorous utilisation management, and credible plans for training and evaluation. Capital is constrained and current guidance stresses disciplined implementation, which suggests that most trusts will need to plan within fixed departmental envelopes, with limited scope to draw on central reserves[1-4]. However, future targeted investment from central government is not impossible, and may be used to support robotic capacity, workforce development and infrastructure, including to stimulate UK clinical excellence and the wider health-tech economy. A clear cash envelope by scenario, such as that presented here, can help commissioners and providers balance ambition with affordability while aligning with NICE evidence requirements[5- 7, 21-23].

The policy relevance of our estimates is bounded by scope, as we priced capital and consumables but did not cost estates, maintenance, financing or leasing, and we did not model clinical outcomes or productivity effects. Workforce is likely to be rate-limiting, with staffing, training time and rota cover shaping achievable throughput and potentially inflating early-year spend. A fuller treatment would couple activity to outcomes and productivity, incorporate whole-life costs and financing options, and embed a realistic workforce ramp-up with training and supervision requirements.

Immediate research priorities include health-economic evidence that should be generated at pace to inform NICE decision making, including prospective cost and outcome data including 30-day morbidity, reintervention, length of stay, 12 month quality of life, and cancer endpoints[5-7]. A ten-year programme of real-world outcomes and productivity measurement should run alongside roll-out, with transparent, periodically updated budget models that incorporate local theatre productivity, replacement cadence, contracting, and open-to-robotic displacement. this should be embedded within NHS evaluation infrastructure and partner audit programmes so that evidence accumulates quickly and informs policy in real time[10-12,19,23]. Living health economic models that can be rapidly updated with new data are needed.

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GAIT statement[24] for Generative AI use: We used a large language model, GPT-5 Thinking (OpenAI; execution date 14 September 2025, Europe/London), to support the study end-to-end: data retrieval and curation, harmonisation of source mappings to OPCS-4 families, scenario design, model specification, code generation and execution, and drafting of text, tables and figures. Human authors reviewed every stage, provided corrective feedback, and take full responsibility for the content. All numerical results are produced by scripted code (Python: pandas, numpy) rather than the LLM. No patient-identifiable information was provided to the LLM. The LLM is not an author and has no responsibility for the work.

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