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Original Article

The Clinical Readiness Tax: How Differences in Preparedness Affect Costs During the Transition to Residency Training in Italy

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Abstract

Background: Efforts to address health workforce shortages have focused mainly on increasing the number of health professionals. Less attention has been paid to how well newly qualified doctors are prepared to contribute to clinical care under supervision when they begin residency. Doctors who start below an expected level of readiness still make a valuable contribution, but it takes longer to realise the full level of productivity expected in the supervised clinical practice. We introduced the clinical readiness tax (CRT), a model-based framework, to quantify the additional resource use associated with delayed activation of clinical human capital.

Methods: We simulated a cohort transitioning to supervised autonomous practice in the Italian postgraduate training system. Productivity thresholds were aligned with the *Entrustable Professional Activity* framework. We calculated the excess resource use through three non-overlapping mechanisms: supervision substitution (senior clinicians' time reallocated to supervision), organisational friction, and capacity effects. Parameters were taken from published literature, administrative data, and national salary schedules. We applied a hospital and societal perspective, and stress-tested the model across optimistic (best-case) and adverse (worst-case) scenarios. Probabilistic sensitivity analysis (PSA) was used to assess parameter uncertainty.

Results: Base-case hospital CRT was €1332 per resident, driven predominantly by additional senior supervision time. Societal CRT was €5249 per resident. In the PSA, mean hospital CRT were €1454 (2.5th-97.5th percentile: €595–€2935), and €5,553 for societal CRT (2.5th-97.5th percentile: €3036–€8585). Across scenarios, hospital CRT ranged from €865 to €4660 and societal CRT from €3998 to €11 319 per resident. Applying the base-case hospital estimate to 14 483 state-funded residency contracts (2024/2025), suggests approximately €19.3 million in national hospital-level productivity losses.

Conclusion: Differences in readiness at the start of residency carry an additional cost for healthcare organisations. The CRT provides a quantitative, model-based approach to connect educational investment to operational efficiency.

Keywords: Health System Efficiency, Economic Evaluation, Human Capital Theory, Postgraduate Medical Education, Entrustable Professional Activities, Workforce Productivity

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Background

A physician's productive contribution to the health system does not abruptly begin at graduation from medical school but is activated progressively, and at varying speed, through the transition to clinical practice.[1] Yet this activation process has received limited attention in workforce policy. The focus was set predominantly on expanding physician supply through increased medical school enrolment and postgraduate training capacity, rather than on the conditions determining how rapidly new entrants become functionally productive in clinical care.[2] Where readiness varies across entry cohorts, the costs of delayed activation are typically absorbed within operational budgets rather than recognised as a distinct category of system expenditure.[1,3]

Italy is a useful setting for this question. Residency is university-based, regulated at a national level, and largely publicly funded: residents are employed by the hospital but they government pays for their positions and salaries. This structure creates a clear separation between the educational system, which prepares graduates, and healthcare providers, which rely on residents as part of supervised service delivery.[4]

The transition from undergraduate medical education to residency has been extensively examined from educational and psychological perspectives, generating important insights into professional identity formation, role adaptation, and performance variability.[5,6] Its implications for health system resource use and operational efficiency, however, remain comparatively underexplored. When new residents have not yet reached the level of competence expected for supervised autonomous practice, healthcare organisations adjust

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Key Messages

Implications for policy makers

- Measure readiness: Use the clinical readiness tax (CRT) to estimate the resource impact of delayed readiness and identify inefficiencies that workforce planning may overlook.
- Invest in transition: Support targeted educational programmes to help doctors reach the expected level of autonomy under supervision.
- Align incentives: Share costs between education and healthcare providers to better align investments in preparation with the benefit of improved readiness.
- Standardise training: Include readiness indicators in objective accreditation frameworks, using entrustable professional activities to define expectations.

Implications for the public

Doctors starting residency are still in training. They look after patients but are still under supervision. The supervision is an essential part of how they learn. Our research shows that when residents arrive with different level of preparedness, the health system may have to pay for it. Improving preparation before and during this transition could help hospitals work more efficiently and allow senior doctors to focus more on patient care. For patients, this means smoother care, fewer delays, and better use of healthcare resources. In the long run, better preparation ensures that public investment in training doctors leads more quickly to safe, high-quality care.

operationally: senior clinicians spend more time supervising, patient throughput may slow, and workflows adapt to lower levels of autonomy.[7,8]

Importantly, these effects should not be interpreted as "costs caused by residents." Supervised training is an essential and valuable component of workforce development, consistent with entrustable professional activity and entrustment-decision frameworks, residents are learners expected to operate under gradually decreasing supervision.[9,10] Rather, the issue is one of timing and activation: when readiness is delayed, the system cannot fully realise the productive contribution residents are expected to provide.[11,12] The resulting gap represents a lost opportunity, a period in which available human capital is present, ready to act, but not yet fully utilised.

This dynamic reflects a broader structural misalignment. Investments in education are made upstream, while the consequences of delayed readiness, such as extended supervision and reduced productivity, are experienced downstream by healthcare providers.[11] These effects represent real resource use, yet they are rarely made visible or evaluated within an economic framework.[4] We conceptualise this misalignment as the clinical readiness tax (CRT): the additional resource intensity imposed on healthcare organisations during the early phase of residency when physicians operate below expected functional thresholds. The term "tax" is metaphorical, an opportunity cost, not a literal financial duty, quantifying the gap between the clinical value residents already contribute under supervision and the higher, more efficient contribution expected once entrustment thresholds are reached. Despite longstanding recognition of transition-to-practice challenges, formal economic evaluation of this phase remains limited, leaving policy-makers without evidence to assess trade-offs between current training structures and upstream interventions such as structured preparatory programmes or simulation-based curricula.[13,14]

We develop a model-based economic framework to estimate system-level costs associated with readiness variation at residency entry within the Italian training system. Italy provides a policy-relevant setting: a large, state-funded infrastructure with nationally standardised entry cohorts, defined salary structures, and accessible administrative data. The analysis aims to inform policy discussions on workforce planning, educational investment, and incentive alignment across the education-to-practice continuum.

Methods

Study Design and Analytical Framework

We conducted a model-based economic evaluation using a stochastic cohort simulation to estimate short-term productivity losses associated with variation in clinical readiness at entry into postgraduate training. The model represents intrinsic resource use during the early phase of residency, when newly qualified physicians transition from closely supervised practice to routine supervised autonomy.

Analyses were performed from both hospital and societal perspectives. The hospital perspective evaluated the operational consequences inside the hospital setting. This included the productivity loss arising when residents, while contributing to care, do not yet operate at their full expected potential, and the additional supervisory time. The societal perspective added two more components: delayed returns on public investment in medical education and resident wage paid when their effective contribution is reduced.

The analytic time horizon was eight months, corresponding to the empirically documented transition-to-autonomy period within the Italian postgraduate training context.[15] Given this short horizon, discounting was not applied. All costs are expressed in 2025 euros. The study followed the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) reporting (Supplementary file 1).

Conceptual Framework and Primary Outcome

The primary outcome is the CRT: the cumulative economic value of excess resource use connected to sub-threshold clinical readiness during the transition-to-autonomy phase. The CRT captures only the marginal resource intensity generated by competence deficits relative to expected entrustment thresholds; not the intrinsic costs of supervised

postgraduate training. This distinction is analytically central to the framework.

Clinical readiness has been well-described by international professional bodies. Competency-based medical education standards specify the level of supervision under which trainees are expected to perform core clinical tasks when entering residency.[16-18] This benchmark reflects the ability to carry out routine activities with indirect supervision, consistent with entrustable professional activities frameworks.[16-18] In this study, we modelled readiness comparing the residents' capacity to perform routine tasks relative to this benchmark. Entry level differs across the cohort and variation around the expected standard translate into differences in supervision needs and realised productivity.

Model Structure

Resident readiness, R(t), grew over time as residents gained skills and clinical exposure under supervision. We assumed linear growth: $R(t) = R_0 + g(t-1)$, on a 1-5 readiness scale. Productivity depended on two entrustment thresholds, $\tau_1 = 2.5$ and $\tau_2 = 3.0$, which reflect the expected levels of resident independence in the Italian national postgraduate training framework 19. Residents below τ_1 worked at reduced productivity, between τ_1 and τ_2 at partial productivity, and above τ_2 at full productivity. We set the monthly growth rate to $g = (\tau_2 - R_0)/(T - 1)$, so that a simulated resident reached τ_2 at the observed transition point, which was month 8 in the base case. The gap between actual and full productivity at each month was applied proportionally to all cost components. Capacity effects were valued at €800 per bed-day (Table 1), and public investment in education was spread over an expected clinical career of 30 years (360 months). Figure 1 shows the structure of the model, and Supplementary file 2 gives all equations and the replication spreadsheet.

Model Inputs and Parameterization

As described in detail in Table 1, the model inputs were derived from a combination of empirical data, administrative sources, published literature, and expert elicitation. Baseline readiness distributions were informed by a previously published study of incoming residents with heterogeneous training backgrounds across the Italian training system.[15]

Productivity coefficients and supervision intensity were estimated using observed clinical supervision patterns and validated with international literature. Parameters related to senior clinician opportunity costs, capacity effects, and organizational efficiency were derived from salary contracts, institutional financial data, and published studies. Conservative parameter assumptions were used to minimize risk of cost overestimation.[15] Supervisor time logs were derived from attending physicians at the same tertiary training hospital over the eight-month transition period; productivity coefficients were derived through a structured exercise in which supervising physicians estimated the proportion of full productivity residents achieved below and at the entrustment threshold, with these estimates cross-checked against the observed supervision-time logs for internal consistency. All model parameters, probability distributions, and deterministic

Table 1. Model Parameters and Assumptions Used in the Clinical Readiness Tax Model

Parameter	Base-Case Value	Distribution	Range	Unit	Data Source/Rationale
Initial readiness (observed cohort) (R)	2.2	Beta	2.0-2.4	Score (1-5)	Empirical cohort assessment at residency entry[15]
Productivity coefficient[a] (low readiness)	0.70	Beta	0.60-0.80	Proportion of full productivity	Expert elicitation validated with supervisor survey
Productivity coefficient[a] (mid readiness)	0.85	Beta	0.75-0.95	Proportion	Same as above
Senior clinician hourly opportunity cost (c_{supp})	63	Gamma	€30-€80	€/hour	Hospital payroll data + literature on specialist wages[20]
Additional supervision time (t_{supp})	12.5	Log-normal	10-35	hours/month	Observed supervisor time logs and literature on early residency supervision[7,8]
Organisational friction factor	10%	Beta	2%-15%	% Efficiency loss	Conservative assumption based on workflow studies in teaching hospitals[21]
Bed-day elasticity (capacity effect)	0.10	Beta	0.05-0.20	Bed-days per month	Literature on marginal productivity and throughput in hospital medicine[21]
Bed-day cost	800	Gamma	600-1200	€/bed-day	Institutional financial data on average inpatient bed-day cost
Time horizon (t)	8	Deterministic	6-12	Months	Empirical duration of transition-to-autonomy phase[15]
Resident wage	2166.67	Gamma	±20%	€/month	National contract for specialist medical training: €26 000/year (fixed + variable components), expressed as €2166.67/month[22]
Public investment per medical graduate	€160 000	Gamma	€120k-€200k	€	OECD and national education expenditure estimates[20]

Abbreviation: OECD, Organisation for Economic Co-operation and Development.

[a] The readiness parameter is the primary driver of model outputs; sensitivity analyses therefore explore both absolute reductions (eg, 1%-5% below expected readiness) and distributional shifts to reflect uncertainty in cohort preparedness.

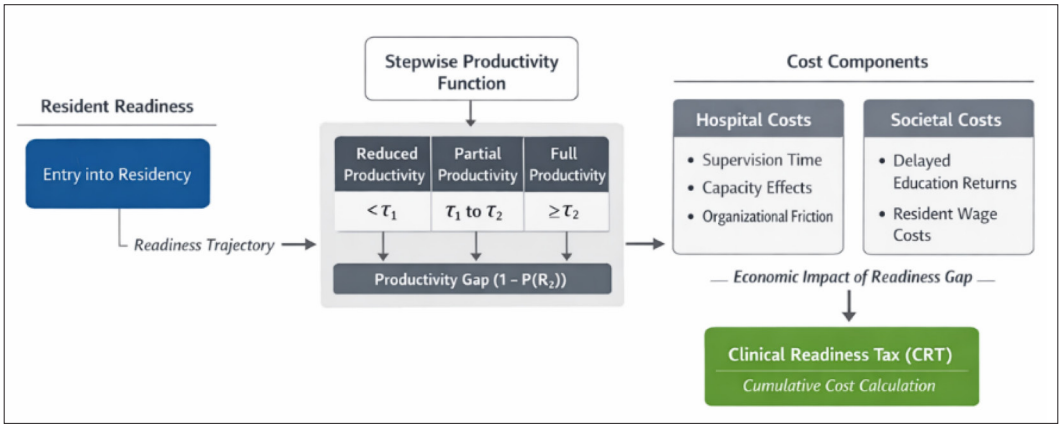

Figure 1. Model Overview of the Clinical Readiness Tax: Resident Readiness at Entry Determines Progression Through a Stepwise Productivity Function, Generating a Productivity Gap. This gap leads to hospital (eg, supervision, capacity) and societal (eg, delayed returns, wages) costs, which together form the cumulative CRT.

sensitivity ranges are presented in Table 1.

Cost Components

Hospital Perspective

The government pays residents through state-funded contracts, so salaries are not a cost to the hospital. The costs here reflect lost production capacity rather than salary expenditure. Three non-overlapping components were included (1) additional supervisory time required from senior clinicians; (2) reduced patient throughput associated with lower resident productivity; and (3) organisational workflow inefficiencies not captured by direct supervision or capacity effects.

Monthly hospital CRT was calculated as the sum of these components and aggregated over the analytic horizon:

$$CRT_{hospital} = \sum_{t=0}^{T} \left(C_{sup}(t) + C_{cap}(t) + C_{fric}(t) \right)$$

Societal-Level Costs

In the societal perspective we included (1) delayed realization of publicly financed medical education investment and (2) resident wage costs during periods of reduced effective productivity.

Total societal CRT combined hospital and societal costs:

$$CRT_{hospital} = \sum_{t=0}^{T} \left(C_{sup}(t) + C_{cap}(t) + C_{fric}(t) \right)$$

In this framework, the education-investment component is described as a delay when the expected return arrives (a timing effect), not as extra spending. Societal costs are therefore reported separately and interpreted with care to avoid double counting with hospital-level productivity losses.

Scenario Analyses

We tested different scenarios chosen for their clinical and policy relevance: high-acuity environments where supervision costs significantly more; a cohort which starts with lower baseline readiness; longer adaptation periods; and an optimized transition where structured preparatory programmed raise readiness at entry. Scenario specifications are detailed in Table 2. These analyses were designed to bound the plausible range of CRT estimates and show where intervention bring the greatest return to the system.

Probabilistic Sensitivity Analysis

To assess parameter uncertainty, we ran a probabilistic sensitivity analysis (PSA) with 10 000 Monte Carlo iterations. Bounded proportions followed Beta distributions, cost and investment parameters followed Gamma distributions, and supervision time followed a log-normal distribution. Each distribution was fitted by moment matching: its mean was the base-case estimate, and its spread was taken from the deterministic sensitivity range in Table 1. In every iteration the readiness growth rate was recalibrated to the sampled entry readiness, so the transition point stayed anchored to the observed data. We report means with 2.5th to 97.5th percentile uncertainty intervals. At 10 000 iterations, Monte Carlo error is negligible at the precision we report.

The scenario analyses were deliberate, fixed parameter settings and not samples from a distribution, so we report them as point estimates. Uncertainty around the parameters is covered by the PSA instead.

The deterministic model, scenario analyses and one-way sensitivity analyses were built in Microsoft Excel. The PSA was run as a script using Phyton. We also recomputed all deterministic outputs independently in Python 3, and they matched the reported values exactly (Supplementary file 2).

Results

Base-Case Analysis

In the base-case analysis, the estimated hospital-level CRT was €1332 per resident over the eight-month transition period. Most of the costs, €1181 (89%) come from supervision substitution, meaning senior clinicians' time diverted to supervising. Capacity effects added €120 (9%) and organisational friction €31 (2%). From a societal perspective, total CRT reached €5249 per resident. The extra costs came from, wages paid during periods of reduced effective productivity (€3250) and delayed return on public investments in their education (€667). Because we choose

Table 2. Scenario Analysis for Hospital Clinical Readiness Tax

Scenario	Description	Key Parameter Modifications	Policy Insight
Base case	Observed transition	R0 = 2.2; Hsup = 12.5; Wsen = €63	Current magnitude of CRT under routine conditions
High-intensity clinical environment	Procedure-heavy specialties	Wsen = €80; Hsup = 20	Shows disproportionate CRT in high-cost settings
Low readiness cohort	Reduced clinical exposure	R0 = 1.8	Illustrates system vulnerability to training variation
Extended adaptation period	Slower productivity growth	T = 12 months	Tests long-term budget implications
Optimized transition program	Preparatory bootcamp	R0 = 2.5; Hsup = 10	Estimates potential ROI of upstream interventions
Efficiency-constrained hospital	High occupancy settings	Forg = 15%; ε = 0.20	Illustrates amplified strain in resource-limited hospitals
Worst case	Combined adverse conditions	R0 = 2.0; Hsup = 20; Wsen = €80; T = 12; Forg = 15%; ε = 0.20	Bounds the plausible upper range of CRT

Abbreviations: CRT, Clinical Readiness Tax; ROI, return on investment.
Legend: R0 = Baseline clinical readiness level at entry into postgraduate training, Hsup = Additional senior clinician supervision time required (hours per month), Wsen = Hourly cost of senior clinician time (€ per hour), T = Duration of the adaptation period (months), Forg = Organisational friction (proportion of inefficiency in workflows), ε (epsilon) = Bed-day elasticity, representing the impact of reduced productivity on hospital capacity.

conservative values, these results can be read as lower bounds rather than central predictions.

Deterministic Sensitivity Analysis

Hospital CRT is primarily driven by supervision time, as illustrated in Figure 2. Supervision hours (10-35/month) show the widest variation in estimates, followed by specialist wages (€30-€80/hour; CRT €699-€1659).

Productivity parameters demonstrate a moderate influence, while baseline readiness (R_0 2.0-2.4) still showing an impact on final costs (€1197-€1468). In contrast, structural factors such as organisational friction, bed-day elasticity, and resident wage show comparatively limited impact on overall CRT. Full sensitivity results are presented in Figure 2.

Probabilistic Sensitivity Analysis

Across 10 000 Monte Carlo iterations, mean hospital CRT was €1454 per resident (2.5th-97.5th percentile: €595-€2935). The distribution was right skewed as high supervision intensity pull the upper tail upwards. Supervision substitution made up for a median 89.6% of hospital CRT across all iterations (P5-P95: 84.5%-93.1%), so it stayed the dominant element however the parameters varied. Mean societal CRT was €5553 per resident (2.5th-97.5th percentile: €3036-€8585). The probability of hospital CRT exceeding €2000 per resident was 21.9%; the probability of total CRT exceeding €7000 was 3.6%. These results confirm that base-case estimates are constant and that the model is not sensitive to extreme parameter combinations.

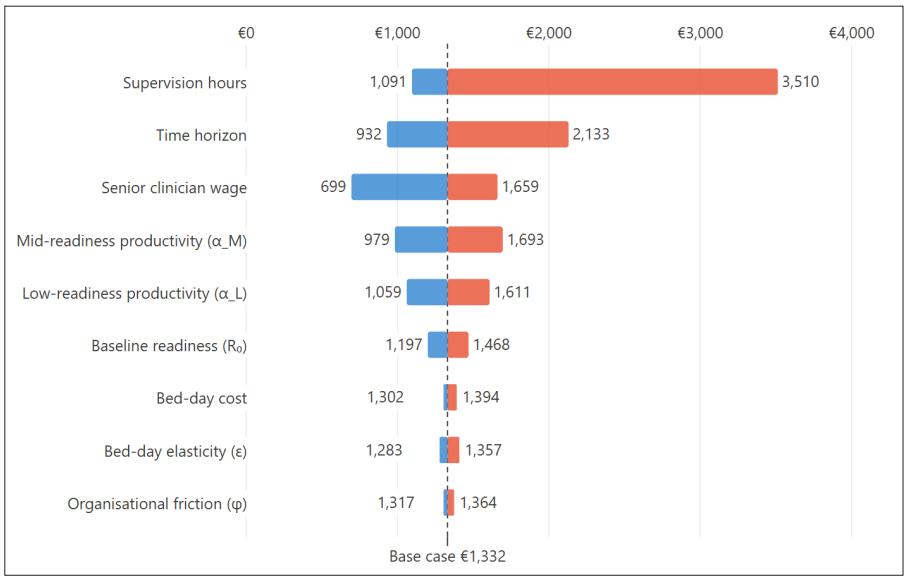

Figure 2. One-Way Sensitivity Analysis of Hospital Clinical Readiness Tax. The figure shows the impact of varying key model parameters on hospital CRT around the base-case estimate (€1332). Results are presented as tornado bars, indicating the range of CRT values obtained when each parameter is varied individually within its defined range. Supervision time and time horizon are the most influential drivers, followed by senior clinician wage and productivity parameters, while organisational friction and capacity-related factors have comparatively smaller effects. Each parameter was varied independently across the deterministic sensitivity ranges reported in Table 1, while all other parameters were held at their base-case values.

Scenario Analyses

Hospital CRT varied from €865 (optimised transition) to €4660 (worst case), with societal CRT ranging from €3998 to €11 319. The base case (€1332 hospital; €5249 societal) lies in the lower range, reflecting conservative assumptions.

Three scenarios are particularly policy relevant. In high-acuity settings, increased supervision time raised hospital CRT to €2580 and societal CRT to €6497. Extending the adaptation period to twelve months increased hospital CRT to €2265 and societal CRT to €8923.

Conversely, an optimised transition, raising baseline readiness from 2.2 to 2.5 and reducing supervision, lowered hospital CRT to €865 and societal CRT to €3998. Compared with the base case, this saves €1251 per resident in societal cost. Compared with the worst case, it saves €7321. With a programme cost of €1000 per resident, the net return is 25% against the base case (break-even at €1251) and 632% against the worst case (break-even at €7321) (Supplementary file 3).

Aggregate System-Level Implications

Applied to Italy's 14 483 state-funded residency contracts, which refer to all government-financed training positions allocated annually to medical graduates (2024-2025 cohort),[22] base-case estimates imply approximately €19.3 million in hospital-level productivity losses and €76.0 million in societal costs. Under the worst-case scenario these figures rise to €67.5 million and €163.9 million respectively; under the optimised transition scenario they fall to €12.5 million and €57.9 million. The gap between worst-case and optimised societal costs, approximately €106 million nationally, is the most that investment in coordinated transition support could recover. These national-level figures should be interpreted as illustrative extrapolations, not as precise estimates. Most of the underlying readiness and supervision parameters were derived from a single tertiary training hospital also they may not hold across specialties, hospital types, and other regions across Italy.

Discussion

This study introduces the CRT as a quantitative concept for estimating the operational costs imposed on healthcare systems when newly qualified physicians enter residency below expected functional thresholds. In the base-case hospital CRT was €1332 per resident. It rose to €4660 under adverse conditions and falling to €865 with structured transition training support. Hospitals absorb such costs in daily routine, so it rarely reaches policy-makers, and does not show in workforce planning models. Once it is measured, residency can be seen as more than supervised training. It also affects how effectively health system use their resources.

Prior economic evaluations of postgraduate medical training have largely focused on the productive contribution of residents once competent, demonstrating the clinical value relative to training costs.[4,23] These analyses, however, implicitly treat the transition to competence as instantaneous. This assumption is inconsistent with a substantial body of educational evidence documenting performance variability, role re-orientation, and adaptive strain during early residency.[24] The CRT framework addresses this gap by modelling the transition period explicitly, quantifying its efficiency consequences, and providing a metric that connects educational investment decisions to operational outcomes. This is distinct from, and complementary to, existing evaluations of resident productivity: where prior work asks how much residents contribute, the CRT asks how efficiently that contribution is activated.

The structural dominance of supervision substitution costs, accounting for 89% of hospital CRT across both base-case and probabilistic analyses, is consistent with evidence from other high-reliability sectors.[25] In aviation, manufacturing, and emergency response, underprepared personnel have been shown to increase supervisory requirements and reduce system throughput by measurable margins.[26,27] The parallel is not merely rhetorical: in each case, the cost of unreadiness is borne not by the training system that produced the gap, but by the operational environment that absorbs it. The CRT framework reframes this cost displacement as a structural feature of systems where training finance and service delivery are institutionally separated, a condition that characterises most national health systems, including Italy's.

The Intervention Logic

The scenario analysis generates a clear intervention logic. The gap between worst-case and optimised societal CRT exceeds €7300 per resident; applied nationally to 14 483 funded contracts, that is, government-financed training positions allocated annually to medical graduates, this implies a recoverable burden of approximately €106 million.[28-31] At an assumed transition-support programme cost of €1000 per resident, the break-even threshold against the base case is €1251, implying a narrow but positive net return even under conservative assumptions. Against the low-readiness scenario, the return on investment exceeds 130%. These figures are only illustrative, and they depend heavily on the assumed €1000 programme cost. Real programme costs, and the supervision residents need throughout the rest of training, were not modelled in detail. They should be interpreted as an order-of-magnitude indication that transition-support investment is plausible, not what a costed programme would deliver.

That does not mean maximising readiness is the goal. Residents learn in complex learning environments where progressive entrustment, cognitive load management, and well-being are legitimate constraints on performance expectations.[32] The CRT model reflects this: productivity thresholds were aligned with entrustment frameworks rather than full autonomous capacity, and conservative parameter assumptions were applied throughout. The policy implication is not to accelerate autonomy prematurely, but to close the gap between observed entry readiness and the threshold at which supervised practice starts to work effectively. This matters for how transition-support programmes are designed. Those built around applied clinical immersion and supervised practice in real settings may return more than purely theoretical preparation.[31]

Heterogeneity and Contextual Variation

The scenario analyses also show that readiness is not spread evenly. High-intensity clinical environments, where supervision needs are high and workload involve many procedures, the hospital CRT of €2580, nearly double the base case. This suggests that the burden of readiness variation is disproportionately concentrated in settings where it is most costly to absorb. Transition support that directs resources toward high-acuity environments and cohorts with lower-readiness are therefore likely to yield the greatest returns to the system.[33] This points toward locally adaptive policy, rather than one uniform standards.

Policy Implications for Centralised System

In the Italian context, the CRT framework has particular relevance given the structural separation between who funds the training and who bears the costs and who entities that finance medical training and those that bear its readiness-related costs. Universities and national funding bodies control undergraduate preparation and residency contract. Teaching hospitals, however, absorb the operational consequences of uneven readiness within regional service delivery budgets.[34]

Residents generate value from the beginning. However, if they enter practice below the level of competence expected for supervised autonomous work, their full productive potential is not immediately realised. This gap does not represent a cost caused by residents, but a loss of potential productivity for hospitals and the wider health system, both in terms of care delivery and additional resource use beyond the cost of education.

This split means the parties involved have different incentives, and the CRT puts a number on the result. Hospital lose about €19.3 million a year nationally in productivity, which is more than what targeted investment in transition support would cost. The framework thus provides a basis for coordinated decision-making across interest-holders, spanning across universities, national funders, regional authorities, and teaching hospitals, whose current incentive structures do not encourage joint investment in transition support.

Limitations

This study has several limitations.

First, the key parameters, including baseline readiness distributions and supervision time logs, came mostly from a single tertiary training hospital. It takes residents from all over Italy, but it may still not represent the full range of Italian training environments.

Second, the findings are specific to the Italian financing model for postgraduate medical education. In Italy, government funding per resident is comparatively low and does not explicitly cover supervisory time. In the Netherlands, Canada and the United Kingdom, per-resident funding is substantially higher and structured differently. CRT estimates should therefore not be carried over to other countries without adaptation.

Third, the model describes an average resident. Individual learning trajectories and supervision needs differ, so the actual CRT will vary considerably from one resident to another.

Fourth, we relied on observational and administrative data and did not measure supervision and workflow disruption continuously. Direct measurement would give more precise parameters and narrower uncertainty intervals.

Fifth, the eight-month horizon captures short-term productivity effects only. Patient safety, career progression and staff retention may also be affected by readiness variation and including them could raise the true economic burden substantially.

Finally, the PSA covered parameter uncertainty, but it could not capture contextual factors we did not measure, such as specialty-specific supervision norms and institutional capacity constraints. These may change the size of the CRT in ways the model does not reflect.

Conclusion

The CRT demonstrates that readiness variation at residency entry may impose real, measurable, and policy-relevant costs on healthcare provider organisations. Today those costs are largely hidden to interest-holder best positioned to address them. At €19.3 million in estimated annual hospital-level losses nationally, and with societal costs reaching €76 million under base-case assumptions, the estimated burden is substantial relative to the investment required to reduce it. In an era of simultaneous workforce shortage and fiscal constraint, transition-support investment is not a marginal educational refinement; it is a mechanism for recovering productive capacity from human capital that has already been publicly financed.

Disclosure of artificial intelligence (AI) use

A generative AI writing assistant (ChatGPT) was used to support language editing and reference formatting during manuscript revision. All analytical content, interpretation, and conclusions are the authors' own and were verified by the authors.

Data availability statement

The Excel-based cohort simulation model, including all parameter distributions and Monte Carlo code, is available from the corresponding author upon reasonable request; anonymised supervisor log data and administrative source extracts underlying the baseline readiness and supervision-time parameters are held by the originating institution and can be shared under a data-use agreement. This study is reported in accordance with the Consolidated Health Economic Evaluation Reporting Standards (CHEERS 2022) checklist for model-based economic evaluations. As the analysis relied on de-identified administrative and supervisory data collected for institutional quality-improvement purposes rather than data collected directly from human participants, it was exempt from separate ethical review; no individually identifiable resident or patient data were used.

Ethical issues

As stated in the manuscript's "Data Availability Statement" section, the analysis relied on de-identified administrative and supervisory data collected for institutional quality-improvement purposes rather than data collected directly from human participants; it was exempt from separate ethical review, and no individually identifiable resident or patient data were used. The exemption was granted by the Humanitas Research Hospital Ethics Committee.

Conflicts of interest

Authors declare that they have no conflicts of interest.

Authors' contributions

Conceptualization: Claudia Ebm and Maurizio Cecconi.
Data curation: Riccardo Sarti.

Formal analysis: Claudia Ebm and Riccardo Sarti.
Methodology: Claudia Ebm and Elena Azzolini.
Project administration: Claudia Ebm.
Resources: Claudia Ebm.
Software: Claudia Ebm and Riccardo Sarti.
Supervision: Holger Schünemann and Maurizio Cecconi.
Validation: Claudia Ebm, Holger Schünemann, Elena Azzolini, and Maurizio Cecconi.
Visualization: Claudia Ebm.
Writing–original draft: Claudia Ebm.
Writing–review & editing: Claudia Ebm, Elena Azzolini, Riccardo Sarti, Holger Schünemann, and Maurizio Cecconi.

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Supplementary files

Supplementary file 1. CHEERS Checklist.
Supplementary file 2. Model Calculations.
Supplementary file 3. CRT Deterministic and Scenario Model.

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