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Buy the Terminal or Make the Airport? A Game-Theoretic Analysis of the Public–Private Partnership Dilemma in Chennai's Second-Airport Decision

Satellite Terminal at Meenambakkam versus Greenfield Airports at Manellore or Cheyyur

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Abstract

Governments adding airport capacity must choose between buying incremental capacity from an incumbent operator and building a new greenfield airport, and between in-house delivery and a public–private partnership (PPP). We model this choice as a multi-stage Stackelberg game among the state, the incumbent, a concessionaire, landowners and a lender. Sites differ in access distance, hazard and land requirements, and contracts face non-contractible effort, renegotiation after a demand shock, lender step-in, minimum revenue guarantees, payment arrears and landowner hold-out. Closed-form equilibria yield ten propositions. A dynamic extension links the incumbent's expansion to the date at which a second airport becomes permissible under a distance-based entry rule, and is solved by simulating 50 years of stochastic demand. Applied to Chennai under an illustrative calibration, a premium-maximising award of the satellite terminal underinvests in capacity, and a capital grant of about 26–33 per cent is welfare-improving. In-house delivery is competitive at the brownfield site, while a PPP is preferred at the greenfield site. Guarantees and arrears raise grant bids and dilute effort. The optimal path buys the satellite terminal now and opens the greenfield on a demand trigger (median about 2046), lowering expected social cost by about ₹12,900 crore relative to building the greenfield alone. Parameters are illustrative pending pre-feasibility data.

Keywords: airport capacity; infrastructure siting; public–private partnerships; incomplete contracts; Stackelberg game; real options

1. Introduction

Airport capacity is infrastructure with a location. Where a state adds capacity, and from whom, fixes access distances, the land to be acquired, hazard exposure and airspace constraints, as well as the contract that delivers it. A government that wants more capacity rarely pours concrete itself: it signs an engineering, procurement and construction (EPC) contract, grants a concession, pays a viability-gap subsidy, guarantees a revenue floor, compensates landowners, or transfers funds to a central agency that does these things for it. The siting decision and the contract decision are therefore one decision. Its quality depends on four things: whether the right capacity is being bought (allocative efficiency); whether rupees become capacity without leakage (technical efficiency); whether the contract survives the future it could not describe (incompleteness and renegotiation); and whether the state has the discipline to stop spending on programmes that no longer earn their keep.

Chennai's airport question in 2026 packs every one of these issues into a single decision. The Meenambakkam airport handled 23.02 million passengers in 2025–26 (Airports Authority of India [AAI] 2026). Its phased modernisation will raise design capacity to about 35 million passengers per annum (MPPA) when Terminal 3 opens around December 2026 (Business Today 2026). Beyond that, AAI has floated a satellite terminal, Terminal 5, on a triangular parcel between the two runways. It is expected to add about 20 MPPA with minimal land acquisition, but it sits on low-lying ground that serves as a natural drainage path for the airfield (DT Next 2026; The News Minute 2026). Meanwhile the state's own greenfield project at Parandur is an estimated ₹27,400 crore airport on about 5,700–5,800 acres, of which some 1,500–1,800 acres had been acquired. In August 2026, after sustained opposition from farmers and residents, the state government announced that it would not proceed with it. This article takes that

announcement as its policy scenario rather than as a settled outcome: *assuming a policy pivot away from Parandur*, which option should replace it? Media reports indicate that the government then shortlisted Manellore (roughly 50–60 km north of the city, about 35 km from the Sriharikota launch range) and Cheyyur (roughly 100 km south, about 35 km from Kalpakkam and 40 km from Puducherry airport, and requiring Ministry of Defence airspace clearance), and asked AAI for a pre-feasibility report (Free Press Journal 2026; Republic World 2026)

The public debate treats these as rival sites. This article argues that they are better understood as rival *contracts*. "Buying" the satellite terminal means purchasing capacity from an incumbent that the state does not control. The incumbent is AAI, whose own long-pending privatisation process for Chennai (Chennai is among the AAI airports listed for leasing in the National Monetisation Pipeline [NITI Aayog and Ministry of Finance 2021], and a request for qualification was reported in December 2024) shapes its incentives. "Making" a greenfield airport means creating a new asset whose value depends on landowners, a concessionaire's unobservable effort, a demand path nobody can contract on, and the state's ability to pay grants on time. Each option can in turn be delivered in-house or contracted out. The decision is therefore a game, and its equilibrium depends on who moves first, what can be verified, and what happens when the future turns out differently from the bid.

The article makes three contributions. First, it models site choice and contract choice jointly: each site enters through access decay, hazard, land and ramp-up parameters, and each can be delivered in-house or through a PPP. This adapts a principal–agent PPP model developed for Indian emergency medical services (Anantharaman 2021), which has a Cobb–Douglas service technology, non-contractible provider effort, renegotiation after a demand shock, and investor step-in when renegotiation fails. The adaptation adds site-specific technical efficiency, an in-house alternative, guarantees, payment arrears and landowner hold-out. Second, it derives closed-form equilibria and propositions for each of the six public-expenditure lenses of Section 3, so that each maps to a testable comparative static. Third, it embeds the contract game in a dynamic Stackelberg game between AAI and the state over 2026–2075. Under a distance-based entry rule, expanding the incumbent postpones the date at which a second site becomes permissible, which makes capacity timing a spatial game. Simulating this over stochastic demand paths yields a concrete, falsifiable recommendation on sequencing and timing.

Section 2 sets out the policy context. Section 3 reviews the literature through the six lenses, identifies the research gap and poses five research questions. Section 4 presents the model and propositions. Section 5 reports the calibration and numerical results. Section 6 discusses policy implications, including which expenditure programmes are worth discontinuing. Section 7 concludes with limitations. Proofs are collected in the Appendix.

2. Policy Context: Chennai's Capacity Problem in 2026

2.1 The incumbent airport

Chennai International Airport (MAA) is owned and operated by AAI on an estate of about 1,300 acres. Traffic recovered after the pandemic to 22.41 million passengers in 2024–25 and 23.02 million in 2025–26, a year-on-year growth of 2.7 per cent (Airports Authority of India [AAI] 2026). AAI has invested about ₹2,467 crore in two modernisation phases. Phase I raised capacity

from 23 to 30 MPPA, and Phase II (Terminal 3) is expected to reach 35 MPPA (Business Today 2026). The proposed Terminal 5 would be a full passenger-and-cargo terminal between the runways, taking the airport towards 55 MPPA. Complementary measures include rapid-exit taxiways to raise runway throughput from about 35 to 45–46 movements an hour, and a public road link that replaces an earlier dedicated elevated corridor, with a cost-sharing arrangement still being negotiated among AAI, the Chennai Unified Metropolitan Transport Authority and the state (The News Minute 2026). No project cost for Terminal 5 had been finalised at the time of writing, and the site's flood exposure requires in-principle approval from the state Water Resources Department.

2.2 The greenfield option after Parandur

Parandur was notified as the second-airport site in 2022. Its history is a textbook case of hold-out: repeated protests by affected villages, political mobilisation, a slowdown of acquisition ahead of the 2026 Assembly election, and, in August 2026, an announcement by the new government that the project would be dropped. The acquired land was reported to be earmarked for industrial use.

Scenario definition. The analysis rests on an explicit policy scenario. *Scenario P0 (policy pivot):* Parandur is not pursued, and the candidate greenfield sites are Manellore and Cheyyur. Terminal 5 remains available as a brownfield option. The model's results are conditional on this scenario. If the policy is reversed, for example if Parandur is revived or a different site is notified, the framework applies unchanged: the new site enters the game through its own access distance, hazard, land and ramp-up parameters, and the Parandur land already acquired would be treated as sunk (Proposition 10). All 2026 developments cited below are reported announcements and plans, not completed actions. They should be re-checked against AAI's pre-feasibility report and state government orders when these are published.

The two candidate replacement sites differ sharply.

Table 1. Capacity options under consideration (September 2026)

Attribute	Satellite terminal T5 (Meenambakkam)	Greenfield, Manellore	Greenfield, Cheyyur
Distance from city	Within existing estate	~50–60 km north	~100 km south
Incremental capacity	~20 MPPA (to ~55 MPPA)	Scalable in phases	Scalable in phases
Land acquisition	Minimal	Large (thousands of acres)	Large (thousands of acres)
Principal site risks	Flood-prone, drainage path; runway system binds	ISRO Sriharikota airspace; coastal wetlands	IAF Tambaram airspace (MoD clearance); Kalpakkam; Puducherry overlap
Likely delivery	AAI in-house, or bundled in a lease of MAA	State-sponsored PPP (DBFOT)	State-sponsored PPP (DBFOT)

Attribute	Satellite terminal T5 (Meenambakkam)	Greenfield, Manellore	Greenfield, Cheyyur
Earliest plausible opening	~2030 (assumed)	~2034 (pre-feasibility + land + 5–7 years' construction)	~2036 (plus defence clearance)

Sources: Official: AAI (2026) traffic statistics; MoCA (2008). Reported plans and announcements (media reports; see the separate reference subsection): Business Today (2026); DT Next (2026); Free Press Journal (2026); Republic World (2026); The News Minute (2026). Opening years are this article's planning assumptions under Scenario P0.

2.3 The regulatory hinge: the 150-kilometre rule

India's Greenfield Airports Policy (Ministry of Civil Aviation [MoCA] 2008) does not ordinarily permit a new greenfield airport within 150 km aerial distance of an existing civilian airport. Proposals inside that radius are examined case by case for their impact on the incumbent. In January 2026 the Union Civil Aviation Minister stated that the restriction "no longer applies" once the incumbent's capacity is saturated (Business Standard 2026). The wider framework for developing airports through AAI, PPPs and state governments is set by the National Civil Aviation Policy 2016 (MoCA 2016), and aeronautical tariffs at major airports are regulated under the Airports Economic Regulatory Authority of India Act, 2008 (Government of India 2008). Both shortlisted sites lie inside the radius. This creates a strategic link that the siting debate has largely missed. Expanding the incumbent postpones saturation, and so postpones the date after which the second airport is unambiguously permissible. Terminal 5 is therefore not only a capacity decision—it is also a move in a timing game.

3. Literature and Conceptual Framework

3.1 Allocative efficiency: public goods versus subsidies

The normative starting point is Samuelson's (1954) condition for public goods, amended by the recognition that public funds are raised through distortionary taxes. Once each rupee of public spending costs society $1 + \lambda$, where λ is the marginal cost of public funds (Ballard et al. 1985; Dahlby 2008), providing a good publicly and subsidising its private provision are no longer equivalent (Atkinson and Stern 1974; Laffont and Tirole 1993). Estimates of λ for developing economies are typically placed around 0.3 or higher (Laffont 2005). Airport capacity is not a pure public good: it is excludable and largely paid for through user charges. Yet it generates consumer surplus and agglomeration benefits that the operator cannot fully capture, and a congested airport imposes spillover costs on the whole metropolitan economy. The allocative question is therefore how far the state should *pay* for capacity rather than *sell* the right to provide it. A premium-maximising concession auction and a grant-minimising viability-gap auction both minimise a fiscal transfer. Neither, in general, maximises welfare. Section 4 formalises this wedge.

3.2 Technical efficiency: translating expenditure into outcomes

Technical efficiency, in the tradition of Farrell (1957), asks whether a given expenditure delivers the maximum feasible output. At the level of whole public sectors, Afonso et al. (2005) show

large cross-country gaps between spending and outcomes. At the project level, the megaproject literature documents systematic cost overruns, delays and demand shortfalls (Flyvbjerg et al. 2003; Flyvbjerg 2014). For India, Ram Singh (2010) attributes much of the overrun in central infrastructure projects to delay, and much of the delay to land, clearances and contractual disputes. In airport economics, efficiency depends on ownership and governance form (Oum et al. 2006; Gillen 2011) and on airside–landside balance and site geometry (de Neufville and Odoni 2013). In this article technical efficiency enters as a site-and-organisation-specific productivity parameter. It captures distance-related access decay, site hazards (flooding, airspace) and the in-house organisation's technical capacity.

3.3 Contracts, incompleteness and renegotiation

The theory of incomplete contracts (Grossman and Hart 1986; Hart and Moore 1990) explains why ownership and residual control matter when relevant actions cannot be written into a contract. Hart et al. (1997) apply the idea to government. A private contractor has stronger incentives to cut costs, but some of those cuts degrade non-contractible quality, so in-house provision is preferred when quality shading is severe. Hart (2003) extends the argument to PPPs by showing when bundling construction with operation is valuable. Bennett and Iossa (2006) and Iossa and Martimort (2015) develop the incentive theory of PPPs. De Bettignies and Ross (2004) survey the economics of PPPs for policy audiences. Engel et al. (2013, 2014) show that a PPP does not create fiscal space in present-value terms. Its value lies in incentives and risk allocation, not in off-balance-sheet finance—a point reinforced by Maskin and Tirole (2008) on how PPPs can be used to evade spending limits.

Renegotiation is the empirical rule rather than the exception. Guasch (2004) and Guasch et al. (2008) document that a large share of Latin American concessions—especially in transport and water—were renegotiated, often soon after award and usually in the operator's favour. They argue that anticipated renegotiation invites aggressive bidding ("low-balling"). De Brux (2010) shows that renegotiation can also be efficiency-enhancing adaptation. Renegotiation is naturally modelled as Nash bargaining (Nash 1950; Binmore et al. 1986). The expectation of ex post rescue is a soft budget constraint (Kornai 1986; Dewatripont and Maskin 1995). The author's doctoral essays modelled precisely this sequence for emergency medical services: a normal-demand PPP contract, a pandemic-like demand shock, renegotiation with a sharing parameter, and—when renegotiation fails—entry of an investor who takes a share of the provider's payoff (Anantharaman 2021; drawing on Elitzur and Gavious 2003). The present model carries that structure to airports.

3.4 Make versus buy and in-house technical capacity

Transaction-cost economics (Williamson 1985) frames the make-or-buy decision around asset specificity, uncertainty and the cost of adaptation. Bajari and Tadelis (2001) show that simple fixed-price contracts are efficient only when projects are well specified. Where design is uncertain, cost-plus contracting and in-house flexibility have value. Levin and Tadelis (2010) find that US cities contract out services that are easy to specify and monitor, and keep in-house those where contracting is hard. A recurring theme is that the ability to buy well depends on the ability to make: a government without in-house engineers can neither specify nor supervise a concession (Iossa and Martimort 2015). For Chennai the relevant in-house organisations are AAI,

experienced in brownfield terminals, and state agencies such as TIDCO, with less greenfield airport experience.

3.5 Delays and payment arrears

Arrears—obligations the government has incurred but not paid on time—are a hidden form of borrowing. Flynn and Pessoa (2014) document their prevalence and the institutional failures that cause them. Contractors price expected delays into bids. Because contractors' cost of capital exceeds the sovereign's, every rupee of delayed payment destroys value. Delays in land acquisition and statutory clearances are, in turn, the main source of time overrun in Indian infrastructure (Ram Singh 2010). Under India's Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013, compensation is set as a statutory multiple of market value. The state's residual lever against hold-out is therefore the speed and generosity of settlement above that floor.

3.6 Transfers, guarantees and programmes worth discontinuing

Guarantees are transfers whose cost is invisible at signature. Irwin (2007) shows how minimum revenue and traffic guarantees shift demand risk onto taxpayers, create contingent liabilities that are rarely valued, and dilute the operator's incentive to build traffic. Engel et al. (2001) propose least-present-value-of-revenue (LPVR) auctions, in which the concession term flexes with demand, as a guarantee-free alternative. On discontinuation, the decision-theory benchmark is that sunk costs are irrelevant. Yet organisations systematically escalate commitment to failing courses of action (Staw 1976; Arkes and Blumer 1985). Real-options theory adds that waiting has value when investment is irreversible and demand is uncertain (Dixit and Pindyck 1994). An expenditure programme is worth discontinuing when its forward-looking marginal social value per rupee falls below the shadow price of public funds, whatever has already been spent. An investment is worth deferring when the option value of waiting exceeds the cost of delay.

3.7 Research gap

Game-theoretic airport studies focus mainly on competition between airports and on regulation (Starkie 2002). The PPP literature is largely sector-neutral. No study, to the author's knowledge, jointly models (i) the brownfield–greenfield choice, (ii) the in-house–PPP choice, (iii) renegotiation, guarantees and arrears, and (iv) the incumbent operator's strategic timing under a distance-based entry rule. Nor has any study applied this to the Indian second-airport problem.

3.8 Research questions

The research gap leads to five research questions:

RQ1 (Allocative efficiency). When airport capacity is procured through a competitive grant or premium auction, does the resulting grant match the welfare-optimal level of public support? If not, under what conditions should the state pay for more capacity than the bidder would supply at the auction price? *(Addressed by Lemma 1 and Proposition 2.)*

RQ2 (Technical efficiency and make versus buy). For the satellite terminal and for each greenfield site, when should capacity be delivered in-house by AAI or a state agency, and when

through a PPP? How does this boundary depend on in-house technical capacity and on how incomplete the contract is? *(Proposition 3.)*

RQ3 (Incomplete contracts, renegotiation and guarantees). When traffic falls short of forecast, how do renegotiation, lender step-in and minimum revenue guarantees affect the operator's effort, the winning grant bid and the state's fiscal exposure? *(Propositions 4–6.)*

RQ4 (Delays and arrears). How do late grant payments and landowner hold-out change bids, investment and welfare? When is compensation above the statutory floor worth paying? *(Propositions 7–8.)*

RQ5 (Sequencing, timing and discontinuation). Given AAI's first move on Terminal 5 and the 150-km rule, should Chennai buy the satellite terminal, make a greenfield airport at Manellore or Cheyyur, or do both in sequence? When should the greenfield open? Which projects and contract features, including Parandur, are worth discontinuing? *(Propositions 9–10; Section 5.3.)*

4. The Model

4.1 Key players

Following the structure of Essay 1 in Anantharaman (2021), the game has five players:

- **Government of Tamil Nadu (G)**: the principal and, for the greenfield, the sponsoring authority. G chooses the site, the delivery mode and the contract instruments.
- **Airports Authority of India (A)**: the incumbent owner-operator of MAA. A decides whether to build the satellite terminal and earns aeronautical and non-aeronautical revenue on the traffic MAA serves.
- **Operator (O)**: a private concessionaire under a PPP, or a public project manager under in-house delivery. O chooses non-verifiable effort and, under a PPP, capacity investment.
- **Landowners (L)**: a representative landowner who accepts the compensation offer or holds out, causing delay.
- **Lender or investor (F)**: steps in with fresh capital for a share of the operator's cash flows when renegotiation fails. F plays the role of the investor in the thesis model.

All players are risk-neutral. The thesis notes that its model extends readily to risk-averse players; the same holds here.

4.2 Options and setting

The site is $m \in \{S, M, C\}$: the satellite terminal at Meenambakkam (S), a greenfield airport at Manellore (M), or a greenfield airport at Cheyyur (C). The delivery mode is $g \in \{H, P\}$: in-house ("make", by AAI or a state agency under EPC contracts) or PPP ("buy", through a design–build–finance–operate–transfer concession). In the dynamic game of Section 4.8, G can also combine options over time or defer.

4.3 Timeline

Fig. 1 summarises the order of play, which mirrors the ordered event timeline of the thesis model:

1. **Stage 0.** AAI decides whether to build the satellite terminal, $x \in \{0,1\}$.

2. **Stage 1.** G selects (m, g). Under a PPP it runs a competitive auction for a capital grant s (a negative s is a premium paid by the concessionaire), and it may offer a minimum revenue guarantee (MRG) with floor $\overline{R}$. G also sets land compensation as a multiple μ of market value.
3. **Stage 2.** Landowners accept or hold out. The expected hold-out delay is $\Delta_m^L(\mu)$.
4. **Stage 3.** The operator chooses effort e (observed only by the operator) and investment I.
5. **Stage 4.** Nature draws demand. With probability $1 - \pi_m$ demand is normal ($\theta = 0$). With probability π_m it is low ($\theta = \overline{\theta}_m$), for example because traffic ramps up slowly at a remote site.
6. **Stage 5.** In the low state the operator seeks renegotiation. G accepts, and the parties split the surplus with bargaining weight β for the operator. Alternatively, with probability q_m, renegotiation fails and a lender steps in for a share δ of the operator's cash flows. Grants are paid with an expected delay of τ years, and guarantees are honoured. Payoffs are realised.

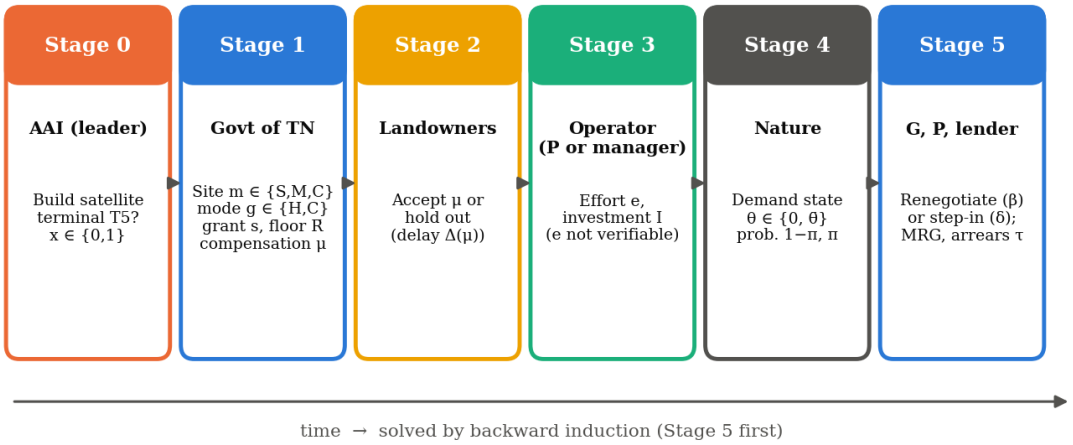

***Fig. 1** Timing of the capacity game. The model is solved by backward induction*

4.4 Assumptions

A1 (Technology). Throughput at site m follows the Cobb–Douglas form of the thesis model, scaled by a demand shifter:

$$Q_m = A_{mg}\, e^{\alpha_1} I^{\alpha_{2m}} \exp(-\theta), \qquad \alpha_1 + \alpha_{2m} < 1. \qquad (1)$$

Where no confusion with effort e can arise, $\exp(x)$ is written e^x. The thesis model sets $\alpha_1 + \alpha_2 = 1$ and treats demand elasticity as a decreasing exponential multiplier. Here a small degree of decreasing returns keeps the investment problem concave. The brownfield has a lower capital elasticity ($\alpha_{2S} < \alpha_{2M} = \alpha_{2C}$) because its fixed runway system limits what additional terminal investment can deliver. Terminal 5 is also capped at $\overline{Q}_S$.

A2 (Site and organisation productivity).

$$A_{mg} = A_0\, \eta_{mg} \exp(-\kappa d_m)\,(1 - h_m), \qquad \eta_{mP} = 1, \;\; \eta_{mH} = \chi_m, \qquad (2)$$

where d_m is the additional access distance from the city, κ is the access-decay rate, h_m is a site-hazard discount (flooding, airspace or defence constraints), and χ_m is the in-house organisation's technical capacity relative to a specialised concessionaire.

A3 (Effort cost). Effort costs $e^2/2$, the quadratic form used in the thesis. Effort is not verifiable, so it cannot be contracted.

A4 (Incomplete contracts). A concessionaire's cost-reducing effort partially degrades non-contractible service quality. This shades the social value of throughput by a factor $(1-\psi)$, in the spirit of Hart et al. (1997). An in-house manager does not shade quality but receives only a low-powered share $\varphi < 1-t$ of the value of throughput.

A5 (Public funds and taxes). Each rupee raised or paid by G costs society $1+\lambda$. The operator pays tax at rate t on revenue rQ. Each unit of throughput generates a net consumer and wider economic benefit k beyond fares.

A6 (Arrears). Grants are paid on average τ years late. The operator discounts at i_O and the government at $i_G < i_O$, so $\rho_O = e^{-i_O\tau} < \rho_G = e^{-i_G\tau}$.

A7 (Fixed development cost and competition). A concessionaire incurs a non-scalable development cost F_m (airside minimum works, utilities). Bidding is competitive, so the winning bid leaves the operator with zero surplus above F_m.

A8 (Land). Land costs μV_m, where V_m is market value and $\mu \geq 2$ reflects the statutory floor for rural land under the 2013 Act. The expected hold-out delay is $\Delta_m^L(\mu) = H_m\, e^{-\gamma(\mu-1)}$.

As in the thesis, $\pi(I,0) = \pi(0,e) = 0$ follows from (1): no investment or no effort means no service.

4.5 Stage 3–5 solution under a PPP

The operator's problem. Let m_L be the share of the marginal low-state revenue that the operator expects to keep. $m_L = 1$ with complete contracts. $m_L = (1-q_m)\beta + q_m(1-\delta)$ with renegotiation and possible step-in (Propositions 4 and 5). $m_L = 0$ under a binding MRG (Proposition 6). Define the effective expected revenue coefficient and the effective unit cost of capital:

$$B_m = (1-t)\, r\, A_{mP}\left[(1-\pi_m) + \pi_m e^{-\overline{\theta}_m} m_L\right], \qquad c = 1-\rho_O s. \qquad (3)$$

The operator solves

$$\max_{e,I}\ \Pi_O = B_m\, e^{\alpha_1} I^{\alpha_2} - \frac{e^2}{2} - c\, I. \qquad (4)$$

Lemma 1 (closed-form equilibrium). Let $\sigma \equiv 1-\alpha_1/2-\alpha_2 > 0$ and $Y \equiv e^{\alpha_1} I^{\alpha_2}$. The unique interior solution of (4) is

$$Y^* = \left[(\alpha_1 B_m)^{\alpha_1/2}\,(\alpha_2 B_m/c)^{\alpha_2}\right]^{1/\sigma}, \quad e^* = \sqrt{\alpha_1 B_m Y^*}, \quad I^* = \frac{\alpha_2 B_m Y^*}{c}, \quad \Pi_O^* = \sigma B_m Y^*. \qquad (5)$$

The analogue in the thesis is the incentive-compatible effort $e^H = [(1-t)\,r\,A\,\alpha_1 I^{1-\alpha_1}]^{1/(2-\alpha_1)}$ for a given public investment. Lemma 1 lets the concessionaire choose I as well, which is the defining feature of a finance-bearing PPP.

Proposition 1 (comparative statics). e^*, I^* and Π_O^* increase in the grant s, in payment punctuality ρ_O, in site productivity A_{mP} and in the retained low-state share m_L. They decrease in the tax rate t, in the size of the demand shock $\overline{\theta}_m$ and in the probability of low demand π_m. *Proof:* Appendix A.1.

Participation and the bid grant. Competition drives the winning grant down to the smallest s that satisfies participation:

$$s_m^b = \min\{\, s \in [\underline{s}, \overline{s}] :\ \sigma B_m Y^*(s) \geq F_m \,\}, \qquad (6)$$

where $\overline{s} = 0.40$ reflects the viability-gap funding ceiling (up to 20 per cent from the Union and up to 20 per cent from the sponsoring authority for economic infrastructure; Department of Economic Affairs [DEA] 2020), and $\underline{s}$ is a lower bound on admissible premiums. If no $s \leq \overline{s}$ satisfies (6), the PPP is not financeable.

Welfare. G evaluates a PPP at site m by

$$W_m^P(s) = D_m \left\{ \Phi\, \overline{Q}_m - \frac{e^{*2}}{2} - I^* + \rho_O s I^* - (1+\lambda)\rho_G s I^* - \Lambda_m - F_m \right\} - (1+\lambda)\mu V_m, \qquad (7)$$

where $\Phi = k(1-\psi) + (1-t)r + (1+\lambda)tr$ is the social value of a unit of throughput, $\overline{Q}_m = A_{mP}\left[(1-\pi_m) + \pi_m e^{-\overline{\theta}_m}\right] Y^*$ is expected throughput (capped at $\overline{Q}_S$ for the brownfield), Λ_m collects the expected costs of renegotiation and guarantees defined below, and $D_m = \exp[-i_G(\Delta_m^c + \Delta_m^L)]$ discounts for construction and hold-out delay.

4.6 The six public-expenditure lenses as propositions

Proposition 2 (allocative efficiency: the bid grant is not the welfare-optimal grant). Evaluated at complete contracts and an interior solution,

$$\frac{dW_m^P}{ds} \ \propto\ [k(1-\psi) + (1+\lambda)tr]\frac{d\overline{Q}_m}{ds} \ -\ [(1+\lambda)\rho_G - \rho_O]I^* \ -\ (1+\lambda)\rho_G\, s\, \frac{dI^*}{ds}. \qquad (8)$$

The three terms are, respectively, the external value of extra capacity, the shadow cost of the transfer, and the cost of the marginal grant-funded investment. The first term is positive whenever $k > 0$ or $t > 0$. Hence, whenever consumer and wider benefits are large relative to the shadow cost of funds, $dW/ds > 0$ at s_m^b, and the welfare-optimal grant s_m^* strictly exceeds the competitive bid. In particular, a premium-maximising award of a profitable brownfield terminal ($s^b < 0$) delivers less capacity than is socially optimal. *Proof:* Appendix A.2.

Proposition 2 is the formal content of the "public good versus subsidy" question. A competitive auction minimises the transfer, not the welfare loss. The operator internalises only after-tax fares, so the state should buy additional capacity *beyond* what the operator would supply at the auction price, until the marginal external value equals the marginal shadow cost of the grant.

Proposition 3 (technical efficiency and make versus buy). Under in-house delivery the manager's effort is $e^H = [\varphi\, r A_{mH} E_m \alpha_1 I^{\alpha_2}]^{1/(2-\alpha_1)}$, with $E_m = (1-\pi_m) + \pi_m e^{-\overline{\theta}_m}$. G chooses I to maximise

$$W_m^H(I) = D_m^H \left\{ [k + (1+\lambda)r] Q_m^H - \frac{(e^H)^2}{2} - (1+\lambda)(I + F_m) \right\} - (1+\lambda)\mu V_m. \qquad (9)$$

There is a threshold of in-house technical capacity $\chi_m^*(\psi)$ such that in-house delivery is preferred iff $\chi_m \geq \chi_m^*(\psi)$. The threshold falls as quality shading ψ rises, as the renegotiation probability or the arrears delay rises, and as in-house execution delay $\Delta_m^H - \Delta_m^c$ falls. *Proof:* Appendix A.3.

In-house delivery wins where the public organisation is technically strong and contracts are hard to complete. PPP delivery wins where the public organisation lacks technical depth and effort matters. This is the Hart–Shleifer–Vishny trade-off expressed as a boundary in the space of (χ, ψ).

Proposition 4 (renegotiation, low-balling and the soft budget constraint). Suppose the low state occurs and renegotiation succeeds. Let V_i and O_i denote continuation and disagreement payoffs. The Nash-bargaining transfer that maximises $(V_O + T - O_O)^\beta\, (V_G - (1+\lambda)T - O_G)^{1-\beta}$ is

$$T^* = O_O - V_O + \frac{\beta\, \Sigma}{1+\lambda}, \qquad \Sigma = (V_G - O_G) + (1+\lambda)(V_O - O_O). \qquad (10)$$

(i) The operator's low-state payoff is $O_O + \beta\Sigma/(1+\lambda)$, so its marginal return to throughput in the low state is scaled by β ($m_L = \beta$): renegotiation dilutes incentives exactly as a soft budget constraint does. (ii) The expected rescue $\pi_m(1-q_m)\beta\Sigma/(1+\lambda)$ enters the participation constraint, so the winning grant bid s_m^b *decreases* in β (low-balling). (iii) Welfare decreases in β, because the lower bid is paid for ex post at shadow price $1+\lambda$ and with weaker effort. *Proof:* Appendix A.4.

Proposition 5 (failed renegotiation and lender step-in). If renegotiation fails (probability q_m), a lender injects I_F for a share δ of low-state cash flows, and its participation requires $\delta(1-t)\, r A_{mP} e^{-\overline{\theta}_m} Y \geq (1+\omega) I_F$. The minimum share is $\delta^* = (1+\omega) I_F / \left[(1-t)\, r A_{mP} e^{-\overline{\theta}_m} Y\right]$. It increases in the shock $\overline{\theta}_m$ and in the lender's required return ω. The operator's low-state incentive becomes $1-\delta^*$, and effort falls accordingly. Service continues, but at lower effort. This mirrors the investor scenario in the thesis, where the investor's share of the service provider's payoff reduces the provider's effort. *Proof:* follows from Lemma 1 with $m_L = 1 - \delta^*$.

Proposition 6 (guarantees). A binding MRG with floor $\overline{R}$ (as a share of normal-state revenue) removes the operator's low-state marginal incentive ($m_L = 0$). Effort and investment therefore fall (Proposition 1). The expected guarantee payout is

$$G_m = \pi_m\, (1-t)\, r A_{mP} Y^* \max\left\{0,\ \overline{R} - e^{-\overline{\theta}_m}\right\}, \qquad (11)$$

with shadow cost $(1+\lambda)G_m$. The liability is zero for $\overline{R} \leq e^{-\overline{\theta}_m}$ and linear above it, and it increases in π_m and $\overline{\theta}_m$. It is therefore largest for the most remote site. Bidders value the guarantee

payout, which pushes s_m^b down. The loss of incentives pushes it up. When the incentive effect dominates, as in the calibration below, the MRG raises the grant bid *and* adds an unbudgeted contingent liability—the worst of both instruments. *Proof:* Appendix A.5.

Proposition 7 (payment arrears). Arrears create a pure deadweight wedge $(\rho_G - \rho_O)\, s\, I^*$: the state saves less by paying late than the operator loses. Because Π_O^* increases in ρ_O, the competitive bid satisfies $\partial s_m^b / \partial \tau > 0$. Late payment is anticipated and priced in, and it lowers both investment and welfare. *Proof:* Appendix A.6.

Proposition 8 (landowner hold-out). G chooses $\mu \geq 2$ to maximise $e^{-i_G[\Delta_m^c + H_m e^{-\gamma(\mu-1)}]}\, \widetilde{W}_m - (1+\lambda)\mu V_m$, where $\widetilde{W}_m$ is the undiscounted operating value. The interior optimum satisfies

$$i_G\, \gamma\, H_m\, e^{-\gamma(\mu^*-1)}\; e^{-i_G \Delta_m(\mu^*)}\; \widetilde{W}_m = (1+\lambda) V_m. \qquad (12)$$

Compensation above the statutory floor pays only when the project's operating value and the hold-out threat are both large. Any alternative that lowers the cost of delay—such as a satellite terminal that absorbs demand in the meantime—lowers μ^* and weakens landowners' bargaining power. Where the hold-out is a political veto ($H_m \to \infty$), no finite μ restores value, and the project should be discontinued (Proposition 10). *Proof:* Appendix A.7.

4.7 Summary of the static game

Given (m, g) and instruments, Stages 2–5 are solved by backward induction. Stage 1 compares $\max_s W_m^P(s)$ subject to (6) with $\max_I W_m^H(I)$ across sites. This gives the site-and-mode equilibrium used in Section 5.1.

4.8 The dynamic Stackelberg game: when to make, and whether to buy first

The static game ranks contracts for a representative project. It does not capture the fact that capacity is needed over time, that demand is uncertain, and that the incumbent moves first. Let annual demand follow a geometric random walk,

$$\ln D_{t+1} = \ln D_t + \mu_D + \sigma_D\, \varepsilon_{t+1}, \qquad \varepsilon \sim N(0,1), \qquad D_{2026} = 23.02. \qquad (13)$$

MAA capacity is $K_t^A = 35 + 20\, x\, \mathbb{1}[t \geq T_5]$. A greenfield at site m opens at T_m with a first phase of K^G MPPA. It adds a second phase four years after utilisation first exceeds 85 per cent. Airlines place a share w of demand at the new airport once it opens (low-cost, cargo and new routes), up to its capacity. MAA serves the remainder up to its capacity, and any excess is spilled. G's expected present-value social cost is

$$\mathcal{C}(x, m, T_m) = \mathbb{E} \sum_{t=2026}^{2075} e^{-i_G(t-2026)} \left[c_{\text{spill}}\, \text{Spill}_t + a_m\, Q_t^G + (1+\lambda)\big(\text{Capex}_t + \text{MRG}_t\big) \right], \qquad (14)$$

where a_m is the extra access cost per passenger using the greenfield. AAI's payoff is $\Pi_A(x) = \mathbb{E} \sum_t e^{-i_G(t-2026)}\, r_A Q_t^A - x\, \text{Capex}_{T5}$.

G's timing strategy is either a fixed opening year or a trigger rule: commit to construction in the first year t in which $D_t \geq h\, K_t^A$, and open ℓ_m years later (land acquisition plus construction). The

trigger rule is the operational form of a real option. Land can be secured early at modest cost, while the irreversible capital is committed only when demand justifies it.

Proposition 9 (sequencing). In the Stackelberg equilibrium: (i) AAI builds the satellite terminal whenever $\Pi_A(1) > \Pi_A(0)$, and this holds whenever the terminal's cost is below the present value of the incremental traffic it serves before a second airport opens. (ii) G's best response to $x = 1$ is a later greenfield opening date than its best response to $x = 0$. (iii) The 150-km rule, interpreted as lapsing at saturation, binds only if G's unconstrained optimum opens the greenfield before MAA saturates. Because opening before saturation diverts traffic, adds access costs and idles capital, that is rarely optimal. (iv) The lower the satellite terminal's cost per MPPA relative to the greenfield's, and the higher the greenfield's access cost, the more "buy then make" is favoured over "make now". The terminal defers the date at which access costs and greenfield capital must be incurred, and it reduces spill in the interim. *Proof:* Appendix A.8; the numerical equilibrium is reported in Section 5.3.

Proposition 10 (discontinuation). Let K_j^{sunk} be expenditure already incurred on project j, K_j^{rem} the remaining cost and Salv_j the salvage value of assets already acquired (for example, land redeployed to industrial use). Continuing j is optimal iff

$$\mathbb{E}W_j - (1+\lambda)K_j^{\text{rem}} \;\geq\; \max_{m \neq j}[\mathbb{E}W_m - (1+\lambda)K_m] + (1+\lambda)\,\text{Salv}_j, \qquad (15)$$

and K_j^{sunk} does not appear. An expenditure programme or contract feature is worth discontinuing when its forward-looking value per rupee falls below $1 + \lambda$. This covers a project facing a political veto, a guarantee whose expected cost exceeds its incentive benefit, and a premium-maximising lease that sacrifices capacity. *Proof:* immediate from the definition of opportunity cost. Sunk costs cancel from both sides of any forward-looking comparison.

5. Calibration and Numerical Results

5.1 Calibration strategy

Airport-specific cost and demand data for the three Chennai options are not yet public: AAI's pre-feasibility study for Manellore and Cheyyur is pending, and no cost for Terminal 5 has been finalised. The calibration is therefore *stylised*. Parameters are anchored where reliable anchors exist (tax rate, viability-gap ceiling, traffic, capacity, distances, the Parandur cost estimate). Elsewhere they are chosen to be plausible and are then stress-tested. The numbers should be read as an illustration of the model's mechanisms and of the direction and rough size of trade-offs, not as a project appraisal. Table 2 lists the static-game parameters. Throughput is scaled so that its units approximate MPPA. Welfare is in model units.

Table 2. Static-game parameters (base case)

Parameter	Symbol	S (T5)	M (Manellore)	C (Cheyyur)	Basis
Effort elasticity	α_1	0.25	0.25	0.25	Thesis structure; decreasing returns

Parameter	Symbol	S (T5)	M (Manellore)	C (Cheyyur)	Basis
Capital elasticity	α_{2m}	0.35	0.45	0.45	Runway constraint at brownfield
Added access distance (km)	d_m	0	50	100	Media reports of site distances
Access decay per km	κ	0.004	0.004	0.004	Assumed; varied 0–0.004
Site hazard	h_m	0.10	0.05	0.08	Flooding; ISRO airspace; IAF/defence airspace
Probability of low demand	π_m	0.15	0.30	0.40	Ramp-up risk rises with remoteness
Size of shock	$\overline{\theta}_m$	0.30	0.50	0.70	As above
In-house technical capacity	χ_m	0.95	0.80	0.80	AAI brownfield experience vs. state agency
Renegotiation failure probability	q_m	0.10	0.30	0.35	Political salience after Parandur
Construction delay, PPP / in-house (yrs)	Δ_m^c, Δ_m^H	1.0 / 1.5	3.0 / 4.0	4.0 / 5.0	Ram Singh (2010) on public-project delay
Hold-out delay at statutory compensation (yrs)	$\Delta_m^L(2)$	0.5	3.0	4.0	Parandur experience; MoD clearance at C
Land cost at $\mu = 2$ / fixed cost	$2V_m$ / F_m	0 / 1.0	3.0 / 6.0	2.5 / 6.0	Relative scale
Capacity cap	$\overline{Q}_m$	20	—	—	T5 ≈ 20 MPPA

Common parameters: $r = 1$; $t = 0.25$ (corporate tax); $k = 0.35$; $\lambda = 0.30$ (Laffont 2005); $i_G = 0.07$, $i_O = 0.12$; $\tau = 1$ year; $\psi = 0.10$; $\varphi = 0.30$; $A_0 = 10$; $\beta = 0.5$; $\delta = 0.35$; MRG floor $\overline{R} = 0.8$; renegotiation surplus $\zeta = 0.25$ of low-state social value; credibility cost of failed renegotiation $\xi = 0.15$; $\gamma = 0.6$; grant range $s \in [-0.5, 0.40]$.

Use of generative AI. The author used Claude (Anthropic), a generative AI assistant, in preparing this manuscript. It helped with gathering background on the Chennai airport projects, synthesising the literature, deriving and numerically checking the model's equilibria, writing the Python code for the calibration and Monte Carlo simulation, producing the figures, and drafting and editing the text. The research problem, the modelling framework adapted from the author's doctoral thesis, the choice of questions and the interpretation of results are the author's. The author reviewed and verified the derivations, code, results and references, and takes full responsibility for the content of this article.

5.2 Static equilibria: which contract at which site?

Table 3 reports the equilibrium of the contract game for each site. The competitive bid grant solves (6). The welfare-optimal grant maximises (7) subject to (6).

Table 3. Equilibrium of the contract game by site and delivery mode

Site	Delivery mode and grant rule	Grant s	Effort e^*	Investment I^*	Throughput $\overline{Q}$	Welfare W
S – Satellite T5	In-house (AAI)	—	1.18	9.3	18.7	14.59
	PPP, complete contract, premium bid	−0.50	1.55	2.2	12.8	12.32
	PPP, complete contract, welfare-optimal grant	0.26	1.94	6.8	20.0 (cap)	**15.76**
	PPP, renegotiation-prone, premium bid	−0.50	1.47	2.0	12.1	11.78
	PPP, renegotiation-prone, welfare-optimal grant	0.33	1.88	7.0	20.0 (cap)	15.55
	PPP with MRG, welfare-optimal grant	0.39	1.82	7.1	20.0 (cap)	15.21
M – Manellore	In-house (state agency)	—	1.09	10.2	15.9	−1.04
	PPP, complete contract, bid grant	0.05	1.88	6.6	18.8	3.76
	PPP, complete contract, welfare-optimal grant	0.40	2.31	14.9	28.6	**5.40**
	PPP, renegotiation-prone, bid grant	0.25	1.86	8.0	20.4	3.93
	PPP, renegotiation-prone, welfare-optimal grant	0.40	2.06	11.9	25.0	4.72
	PPP with MRG, bid grant	0.36	1.72	7.8	19.8	2.71
C – Cheyyur	In-house (state agency)	—	0.74	4.7	7.3	−4.36

Site	Delivery mode and grant rule	Grant s	Effort e^*	Investment I^*	Throughput $\overline{Q}$	Welfare W
	PPP, complete contract (at 40% ceiling)	0.40 ✗	1.57	6.9	13.1	−1.40
	PPP, renegotiation-prone (at 40% ceiling)	0.40 ✗	1.36	5.2	11.2	−1.73
	PPP with MRG (at 40% ceiling)	0.40 ✗	1.12	3.5	8.9	−2.98

Note: ✗ = not financeable. The participation constraint (6) fails even at the 40 per cent viability-gap ceiling. Welfare is in model units and is comparable within the table. The premium bid for T5 is at the lower bound of admissible premiums.

Five findings emerge.

(a) Selling the satellite terminal to the highest bidder buys too little capacity (Proposition 2). At the brownfield a concessionaire would pay a premium, but a premium-maximising award leaves throughput at about 12 MPPA-equivalent against a cap of 20. A welfare-optimal grant of about 26–33 per cent of capital cost fills the terminal and raises welfare by 3.4–3.8 units (Fig. 2a). This is the allocative-efficiency result in its sharpest form. A profitable asset still justifies public money, because the operator does not capture the congestion relief and wider benefits of the extra capacity. It also cautions against bundling Terminal 5 into a revenue-maximising lease of MAA of the kind contemplated in AAI's privatisation process.

(b) The brownfield is a close make-or-buy call; the greenfield is not (Proposition 3). AAI's in-house delivery of T5 (W = 14.59) comes within 7 per cent of the best PPP (15.76). The threshold in-house capacity is $\chi_S^* \approx 0.98$ at the base level of quality shading and 0.94 when shading is severe ($\psi = 0.3$). With $\chi_S = 0.95$, AAI is right at the boundary (Fig. 4a). If contracting a terminal inside a live airfield raises quality shading above $\psi \approx 0.25$, in-house delivery is preferred. At Manellore the threshold is $\chi_M^* \approx 1.02$: a state agency would need to *exceed* a specialised concessionaire's technical capability for in-house delivery to win (Fig. 4b). Technical capacity, not ideology, draws the make-or-buy line.

(c) Renegotiation and guarantees destroy value in distinct ways (Propositions 4 and 6). Moving from complete contracts to a renegotiation-prone contract at Manellore lowers attainable welfare from 5.40 to 4.72. Adding an MRG lowers it further, to about 2.9. Under the bid rule the MRG *raises* the grant bid (from 0.05 to 0.36), because the loss of low-state incentives outweighs the value of the guarantee. Taxpayers therefore pay a larger grant *and* carry a contingent liability. Fig. 3b shows low-balling: as the concessionaire's expected share of renegotiation surplus rises from 0.1 to 0.9, its winning grant bid falls from 0.38 to 0.11, while welfare falls from 4.14 to 3.66. A cheap bid in a renegotiation-prone environment signals expected rescue, not efficiency. Fig. 3c shows that the MRG liability is zero until the floor exceeds the low-state revenue ratio ($e^{-\overline{\theta}_M} \approx 0.61$) and rises steeply beyond it.

(d) Arrears are priced in (Proposition 7). Raising the expected delay in paying the grant from zero to four years raises Manellore's winning bid from 0.22 to 0.35 of capital cost and lowers welfare from 4.01 to 3.68 (Fig. 3a). Paying on time is itself a subsidy reform, and a costless one.

(e) Cheyyur is not financeable, and should not be started on current parameters (Proposition 10). No PPP clears participation at the 40 per cent ceiling, and in-house delivery has strongly negative welfare. Cheyyur's disadvantages compound: distance lowers productivity, remoteness raises ramp-up risk, and defence airspace adds delay. A PPP becomes financeable only if the access-decay rate falls to about a quarter of its base value ($\kappa \leq 0.001$), for instance through a high-speed rail link or a sharp southward shift of the demand centre. Even then Manellore remains ahead (W = 5.95 against 3.11).

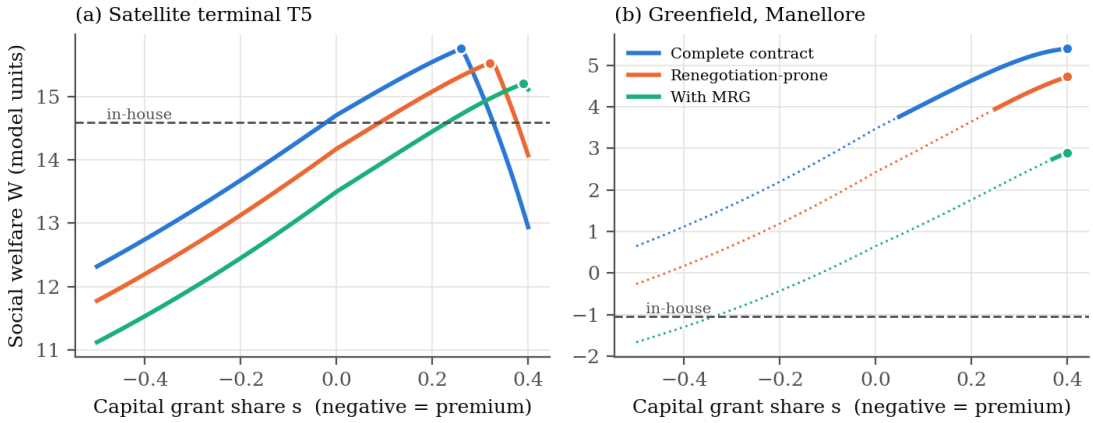

Fig. 2 *Social welfare as a function of the capital grant share. Dotted segments violate the concessionaire's participation constraint; dots mark the welfare-optimal grant; the dashed line is in-house delivery*

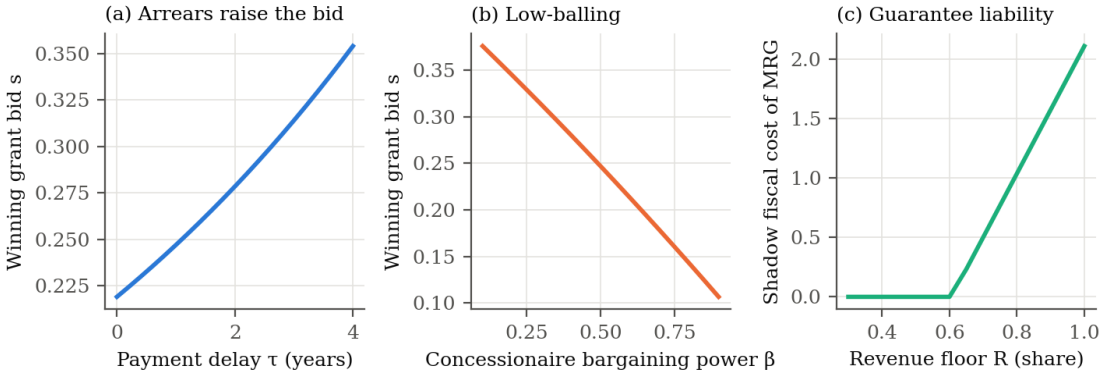

Fig. 3 *Contract features and fiscal exposure at Manellore: (a) payment arrears and the grant bid; (b) low-balling as the concessionaire's renegotiation bargaining power rises; (c) shadow fiscal cost of a minimum revenue guarantee as the floor rises (grant fixed at 20 per cent)*

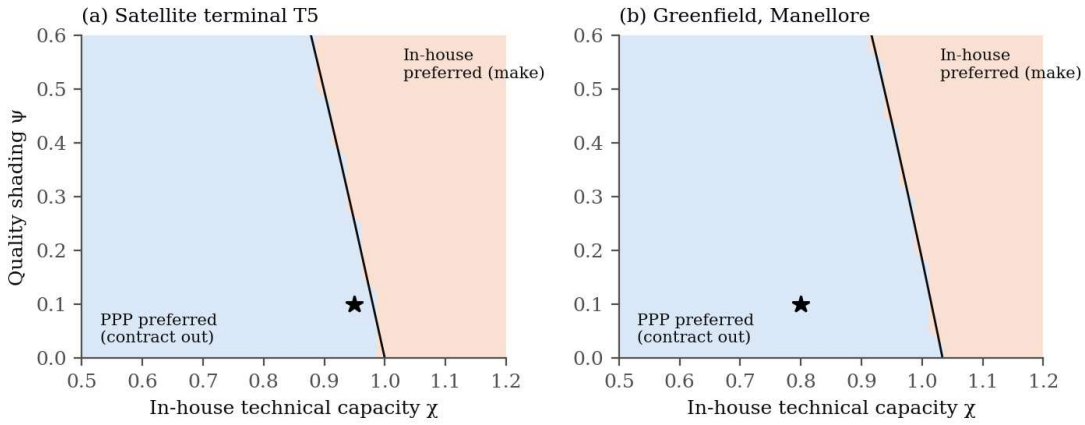

Fig. 4 *Make-or-buy boundaries. Shaded regions show where in-house delivery or a PPP maximises welfare. Stars mark the base calibration*

Land hold-out (Proposition 8). For Manellore the optimal compensation multiple equals the statutory floor ($\mu^* = 2$). Paying above the floor raises welfare only if the expected hold-out delay at statutory compensation exceeds about nine years, three times the base assumption. For Cheyyur, whose operating value is too low to protect, no premium is justified. The more important lever is indirect: every year of capacity that Terminal 5 supplies lowers the cost of greenfield delay, and with it the value of the landowners' hold-out threat.

5.3 Dynamic results: buy, make, or buy then make?

Table 4 lists the parameters of the dynamic game. Capital costs are expressed in ₹ crore at 2026 prices and are illustrative. The greenfield first-phase cost is scaled to the ₹27,400 crore Parandur estimate once land and connectivity are included. The Terminal 5 cost is an assumption pending AAI's estimate.

Table 4. Dynamic-game parameters (base case)

Parameter	Value
Demand 2025–26; trend growth μ_D; volatility σ_D	23.02 MPPA; 5.5% p.a.; 5% p.a.
MAA capacity after T3; T5 increment; T5 opening; T5 capital cost	35 MPPA; +20 MPPA; 2030; ₹9,000 crore
Greenfield phase 1 / phase 2 capacity	30 / +30 MPPA
Greenfield phase 1 capital (M / C); phase 2	₹20,000 / ₹21,000 crore; ₹12,000 crore
Land (M / C); connectivity (M / C)	₹3,000 / ₹2,500 crore; ₹5,000 / ₹8,000 crore
Lead time from decision to opening (M / C); earliest opening	6 / 7 years; 2034 / 2036
Extra access cost per greenfield passenger (M / C)	₹450 / ₹900
Welfare loss per spilled passenger	₹3,000
Share of demand placed at a new airport	15%
MRG: traffic floor; revenue shortfall per passenger	10 MPPA; ₹600

Parameter	Value
AAI revenue per passenger	₹800
Discount rate; shadow cost of funds	7% real; λ = 0.30
Horizon; Monte Carlo paths	2026–2075; 900 (600 for sensitivity)

Fig. 5 shows the demand fan. Under trend growth the enlarged Meenambakkam saturates at a median of **2034 without Terminal 5** and **2042 with it**. Table 5 and Fig. 6 compare the strategies. Each greenfield strategy uses its cost-minimising demand trigger.

Table 5. Expected present-value social cost of capacity strategies, 2026–2075 (₹ crore)

Strategy	Spilled demand	Access cost	Shadow fiscal cost	Total	Median greenfield opening
Buy then make: T5 + Manellore (trigger 0.9)	39,901	6,109	24,992	**71,002**	2046
Buy then make: T5 + Cheyyur (trigger 0.9)	41,238	11,784	25,326	78,348	2047
Make now: Manellore, no T5 (trigger 1.0)	53,025	9,299	21,535	83,859	2040
Buy only: satellite T5	80,245	0	10,188	90,433	—
Make now: Cheyyur, no T5 (trigger 1.0)	54,962	18,015	22,077	95,054	2041
Status quo: T3 only	115,002	0	0	115,002	—
Premature commitment: T5 + Manellore fixed for 2034	—	—	—	*85,564*	2034
Premature commitment: Manellore fixed for 2034, no T5	—	—	—	*89,302*	2034

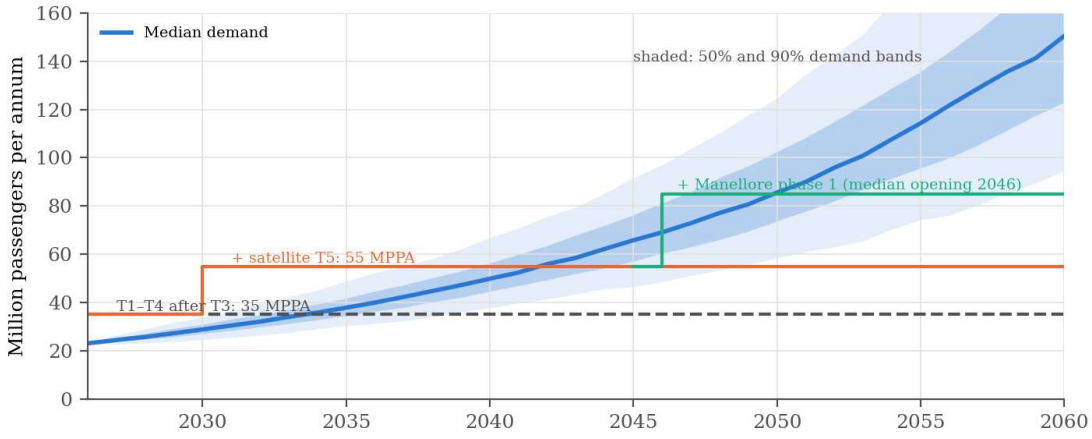

Fig. 5 *Demand fan (median, 50 per cent and 90 per cent bands) against the capacity stack under the "buy then make" strategy with Manellore*

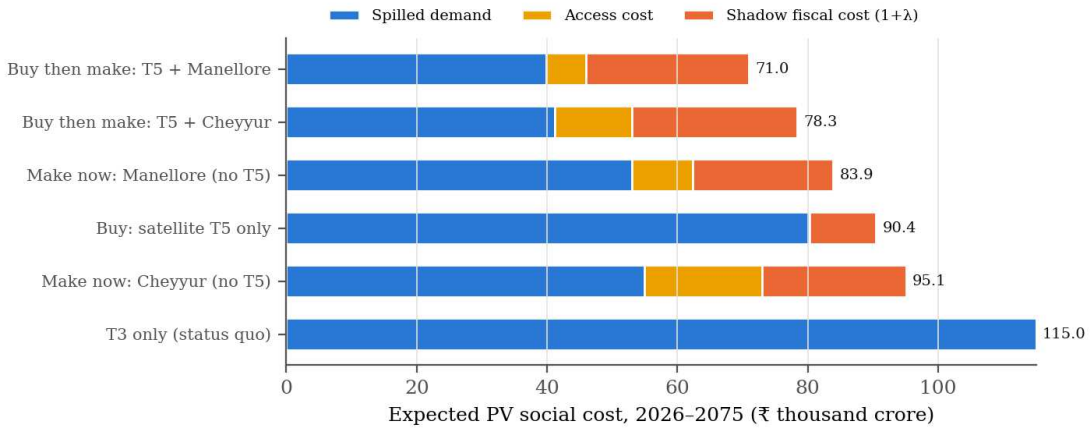

Fig. 6 *Expected present-value social cost by strategy, decomposed into spilled demand, access cost and shadow fiscal cost*

The results support Proposition 9.

1. **AAI's move.** AAI's expected aeronautical and non-aeronautical revenue, net of the terminal's cost, is ₹37,553 crore with Terminal 5 against ₹36,220 crore without it. Building the terminal is AAI's best move regardless of the state's timing.
2. **The state's best response.** Given Terminal 5, the state's cost-minimising strategy is to secure Manellore and start construction when demand reaches about 90 per cent of the enlarged incumbent's capacity. The median opening is then 2046. Without Terminal 5, the optimal opening moves forward to about 2040.
3. **Sequencing dominates.** "Buy then make" with Manellore costs ₹71,002 crore. That is ₹12,857 crore less than making Manellore alone, ₹19,431 crore less than buying Terminal 5 alone, and ₹7,346 crore less than the same sequence with Cheyyur.
4. **Commitment is costly; flexibility is valuable.** Fixing a 2034 opening today, as political pressure after Parandur might suggest, raises cost by ₹14,562 crore. The demand-trigger rule beats the best fixed opening year (2045) by about ₹700 crore—the value of keeping the option open.
5. **The 150-km rule does not bind at the optimum.** The optimal greenfield opening (2046) falls *after* the incumbent's median saturation year with Terminal 5 (2042). The minister's reading of the rule therefore imposes no constraint on the efficient path. It would bind only on a premature opening, which the model shows to be inefficient on its own terms.

5.4 Sensitivity analysis

Table 6. Robustness of the strategy ranking

Scenario	Best strategy (median opening; ₹ crore)	Runner-up (₹ crore)
Base case	T5 + Manellore (2046; 70,081)	T5 + Cheyyur (77,306)
High growth, μ_D = 7.5%	T5 + Manellore (2043; 194,826)	T5 + Cheyyur (206,391)

Scenario	Best strategy (median opening; ₹ crore)	Runner-up (₹ crore)
Low growth, μ_D = 3.5%	T5 + Manellore (2057; 23,458)	T5 + Cheyyur (25,946)
T5 late (2035) and only +12 MPPA	T5 + Manellore (2047; 76,364)	Manellore now (82,470)
Cheyyur access cost halved	T5 + Manellore (2046; 70,081)	T5 + Cheyyur (71,518)
High shadow cost of funds, λ = 0.6	T5 + Manellore (2048; 75,559)	T5 + Cheyyur (82,738)
Low value of a spilled trip (₹1,500)	T5 + Manellore (2050; 49,176)	T5 only (49,608)

Note: The sensitivity runs use a different random seed and 600 paths, so the base-case total differs slightly from Table 5.

The sequential strategy with Manellore is optimal in every scenario. What moves is the *timing*. Faster growth pulls the greenfield opening forward to the early 2040s, and slower growth pushes it to the late 2050s. A late or smaller Terminal 5 narrows the margin over "Manellore now" to about ₹6,100 crore, which shows that the case for buying first rests on AAI delivering the terminal on time and at scale. Halving Cheyyur's access penalty nearly closes its gap with Manellore (₹1,437 crore). The Manellore–Cheyyur choice is therefore at bottom a question about where Chennai's demand will be and how fast it can reach the site. When a spilled trip is valued low, building nothing beyond Terminal 5 becomes competitive, which underlines that the case for any second airport rests on the value society places on unserved demand.

6. Discussion and Policy Implications

Table 7. Answers to the research questions

Research question	Answer from the model
RQ1 Allocative efficiency	No. Competitive auctions minimise the transfer, not the welfare loss. A welfare-optimal grant of about 26–33 per cent fills Terminal 5, where a premium auction would leave it well short of capacity.
RQ2 Make versus buy	Terminal 5 is a close call (in-house delivery is within about 7 per cent of the best PPP). A greenfield favours a PPP unless in-house capacity matches a specialist concessionaire.
RQ3 Renegotiation and guarantees	Renegotiation weakens effort and invites low bids. Minimum revenue guarantees raise the grant bid and add a contingent liability.
RQ4 Delays and arrears	Arrears are priced into bids (grant bid rises from 0.22 to 0.35 with four years' delay). Statutory compensation is optimal unless hold-out delay exceeds about nine years.
RQ5 Sequencing and discontinuation	Buy Terminal 5 now, secure Manellore, and open it on a demand trigger (median opening about 2046). Cheyyur is not financeable on

Research question	Answer from the model
	current parameters. Sunk land at Parandur should not drive the next decision.

6.1 Answering the dilemma

The question "should Chennai buy the satellite terminal or make a greenfield airport?" poses a false dichotomy. The equilibrium answer is *both, in sequence, under different contracts*. Terminal 5 is a near-term, low-land, brownfield increment. AAI has both the incentive and the technical capacity to deliver it, and in-house delivery or a grant-supported PPP both perform well. The greenfield is a long-dated option, and the state's job is to buy the option cheaply now (site selection, land, clearances) and exercise it on a demand trigger. Manellore dominates Cheyyur on access, ramp-up risk and financeability unless the geography of demand changes.

6.2 Allocative efficiency: stop selling capacity by the rupee

Viability-gap and premium auctions minimise fiscal transfers. They do not maximise welfare. For Terminal 5 the model recommends against a revenue-maximising award. If Terminal 5 enters a future lease of MAA, the lease should carry binding capacity obligations and a capital contribution calibrated to congestion relief, not the highest per-passenger fee. For the greenfield, the grant should be set with a view to the capacity it buys, within the 40 per cent ceiling, rather than treated as a residual.

6.3 Technical efficiency and in-house capacity

The make-or-buy boundary is technical, not ideological. AAI's brownfield experience makes in-house delivery of Terminal 5 competitive. The state has no comparable greenfield capability, so a PPP is preferred for Manellore. The corollary is that the state needs *enough* in-house engineering and contract-management capacity to specify, monitor and renegotiate a concession. That capacity lowers quality shading ψ, and it is cheap relative to the value at stake.

6.4 Contracts: design for the renegotiation that will come

Four design rules follow from Propositions 4–7:

1. **Replace minimum revenue guarantees with demand-flexible terms.** An LPVR concession, whose term extends when traffic is low (Engel et al. 2001), or a revenue-sharing band, transfers ramp-up risk without killing incentives.
2. **Pre-specify renegotiation triggers and a bargaining protocol.** Independent traffic audits, a formula for extending the term, and a cap on transfers lower the operator's effective bargaining power β and the scope for low-balling.
3. **Make step-in credible but costly for the operator.** Substitution rights for lenders keep the airport open after renegotiation fails (Proposition 5). They should dilute the original sponsor's equity, not taxpayers' funds.
4. **Ring-fence grant payments.** An escrow funded before financial close removes the arrears wedge. Because arrears are priced into bids, on-time payment lowers the grant the state must offer.

6.5 Expenditure programmes worth discontinuing

Applying Proposition 10 identifies four candidates. (i) **Parandur**, under Scenario P0. The acquired land is sunk for siting purposes. Its industrial reuse value is a salvage value that belongs in the accounts, but it should not tilt the next airport decision towards or away from Parandur's orbit. (ii) **Cheyyur as a stand-alone PPP**, under current access conditions: the pre-feasibility study should test the access-cost assumption explicitly before resources are committed. (iii) **Open-ended minimum revenue guarantees** in any airport concession. (iv) **Premium-maximising award rules** for capacity-constrained brownfield assets. More generally, the decision to discontinue should turn on forward-looking value per rupee relative to $1 + \lambda$. Resisting sunk-cost escalation (Staw 1976; Arkes and Blumer 1985) matters as much as the decision to begin.

6.6 Transfers and guarantees as fiscal instruments

The model's shadow fiscal cost term, $(1 + \lambda)(\text{Capex} + \text{MRG})$, accounts for about 35 per cent of the expected social cost of the optimal strategy. Grants, guarantees and connectivity spending should be evaluated as one transfer package. The contingent liability from guarantees and the connectivity bill, which is higher for Cheyyur, should be disclosed in the state budget alongside the headline viability-gap grant (Irwin 2007).

7. Conclusion, Limitations and Future Research

This article recasts Chennai's second-airport debate as a problem of contracts and transfers. It extends a principal–agent PPP model from Indian emergency medical services to airport capacity, derives closed-form equilibria for six public-expenditure lenses, and embeds them in a Stackelberg timing game with the incumbent operator. Under a stylised but transparent calibration, the recommended path is to buy the satellite terminal, secure Manellore, and make the greenfield on a demand trigger. The contracts should use grants sized to capacity, avoid revenue guarantees, pre-specify renegotiation, and pay on time.

The limitations are clear. The calibration is illustrative, and the project-level parameters must be replaced with AAI's pre-feasibility data, AERA tariff determinations and survey-based access costs once available. Demand is modelled at the level of the whole region, without airline network effects or competition from Bengaluru, Tirupati or Puducherry. The landowner game is reduced to a single representative agent. Collective action among many landowners, and the political economy of protest, deserve a model of their own (for example, a war of attrition). The flood risk at Terminal 5 enters only as a productivity discount. Climate-adjusted drainage costs could make the brownfield option materially more expensive. Future work should (i) estimate χ and ψ from Indian airport and highway contracts, (ii) model the MAA privatisation and a greenfield concession as competing concessionaires with rights of first refusal, and (iii) test the demand-trigger rule against an explicit stochastic dynamic programme.

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Note on sources and scenario: Policy and regulatory facts are cited from official documents (MoCA, DEA, NITI Aayog, AAI traffic statistics and Acts of Parliament). The 2026 site decisions define Scenario P0 and are cited from media reports, which are listed separately. The results are conditional on that scenario and should be re-verified against AAI's pre-feasibility report and state government orders when these are published.

References

Afonso A, Schuknecht L, Tanzi V (2005) Public sector efficiency: An international comparison. *Public Choice* 123:321–347

Airports Authority of India (2026) AAI traffic news: Airport-wise passenger traffic, April 2025–March 2026 [Statistical annexures]. https://www.aai.aero/en/business-opportunities/aai-traffic-news

Anantharaman SK (2021) Essays on modelling public-private-partnerships (PPP) for Indian emergency medical services. Doctoral thesis, Fellow Programme in Management, Indian Institute of Management Indore

Arkes HR, Blumer C (1985) The psychology of sunk cost. *Organizational Behavior and Human Decision Processes* 35:124–140

Atkinson AB, Stern NH (1974) Pigou, taxation and public goods. *Review of Economic Studies* 41:119–128

Bajari P, Tadelis S (2001) Incentives versus transaction costs: A theory of procurement contracts. *RAND Journal of Economics* 32:387–407

Ballard CL, Shoven JB, Whalley J (1985) General equilibrium computations of the marginal welfare costs of taxes in the United States. *American Economic Review* 75:128–138

Bennett J, Iossa E (2006) Building and managing facilities for public services. *Journal of Public Economics* 90:2143–2160

Binmore K, Rubinstein A, Wolinsky A (1986) The Nash bargaining solution in economic modelling. *RAND Journal of Economics* 17:176–188

Dahlby B (2008) The marginal cost of public funds: Theory and applications. MIT Press

de Bettignies J-E, Ross TW (2004) The economics of public-private partnerships. *Canadian Public Policy* 30:135–154

de Brux J (2010) The dark and bright sides of renegotiation: An application to transport concession contracts. *Utilities Policy* 18:77–85

de Neufville R, Odoni A (2013) Airport systems: Planning, design, and management, 2nd edn. McGraw-Hill

Department of Economic Affairs, Ministry of Finance, Government of India (2020) Scheme for financial support to public private partnerships in infrastructure (Viability Gap Funding Scheme): Revised guidelines. Government of India

Dewatripont M, Maskin E (1995) Credit and efficiency in centralized and decentralized economies. *Review of Economic Studies* 62:541–555

Dixit AK, Pindyck RS (1994) Investment under uncertainty. Princeton University Press

Elitzur R, Gavious A (2003) Contracting, signaling, and moral hazard: A model of entrepreneurs, 'angels,' and venture capitalists. *Journal of Business Venturing* 18:709–725

Engel E, Fischer R, Galetovic A (2001) Least-present-value-of-revenue auctions and highway franchising. *Journal of Political Economy* 109:993–1020

Engel E, Fischer R, Galetovic A (2013) The basic public finance of public–private partnerships. *Journal of the European Economic Association* 11:83–111

Engel E, Fischer R, Galetovic A (2014) The economics of public-private partnerships: A basic guide. Cambridge University Press

Farrell MJ (1957) The measurement of productive efficiency. *Journal of the Royal Statistical Society, Series A* 120:253–290

Flynn S, Pessoa M (2014) Prevention and management of government expenditure arrears (Technical Notes and Manuals 14/01). International Monetary Fund

Flyvbjerg B (2014) What you should know about megaprojects and why: An overview. *Project Management Journal* 45:6–19

Flyvbjerg B, Bruzelius N, Rothengatter W (2003) Megaprojects and risk: An anatomy of ambition. Cambridge University Press

Gillen D (2011) The evolution of airport ownership and governance. *Journal of Air Transport Management* 17:3–13

Government of India (2008) The Airports Economic Regulatory Authority of India Act, 2008 (Act No. 27 of 2008)

Government of India (2013) The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013 (Act No. 30 of 2013)

Grossman SJ, Hart OD (1986) The costs and benefits of ownership: A theory of vertical and lateral integration. *Journal of Political Economy* 94:691–719

Guasch JL (2004) Granting and renegotiating infrastructure concessions: Doing it right. World Bank

Guasch JL, Laffont J-J, Straub S (2008) Renegotiation of concession contracts in Latin America: Evidence from the water and transport sectors. *International Journal of Industrial Organization* 26:421–442

Hart O (2003) Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships. *Economic Journal* 113:C69–C76

Hart O, Moore J (1990) Property rights and the nature of the firm. *Journal of Political Economy* 98:1119–1158

Hart O, Shleifer A, Vishny RW (1997) The proper scope of government: Theory and an application to prisons. *Quarterly Journal of Economics* 112:1127–1161

Iossa E, Martimort D (2015) The simple microeconomics of public-private partnerships. *Journal of Public Economic Theory* 17:4–48

Irwin TC (2007) Government guarantees: Allocating and valuing risk in privately financed infrastructure projects. World Bank

Kornai J (1986) The soft budget constraint. *Kyklos* 39:3–30

Laffont J-J (2005) Regulation and development. Cambridge University Press

Laffont J-J, Tirole J (1993) A theory of incentives in procurement and regulation. MIT Press

Levin J, Tadelis S (2010) Contracting for government services: Theory and evidence from U.S. cities. *Journal of Industrial Economics* 58:507–541

Maskin E, Tirole J (2008) Public–private partnerships and government spending limits. *International Journal of Industrial Organization* 26:412–420

Ministry of Civil Aviation, Government of India (2008) Greenfield Airports Policy. https://www.civilaviation.gov.in/ministry-documents/airports-documents

Ministry of Civil Aviation, Government of India (2016) National Civil Aviation Policy 2016. Government of India

Nash J (1950) The bargaining problem. *Econometrica* 18:155–162

NITI Aayog and Ministry of Finance, Government of India (2021) National Monetisation Pipeline, Volume II: Asset pipeline. NITI Aayog

Oum TH, Adler N, Yu C (2006) Privatization, corporatization, ownership forms and their effects on the performance of the world's major airports. *Journal of Air Transport Management* 12:109–121

Ram Singh (2010) Delays and cost overruns in infrastructure projects: Extent, causes and remedies. *Economic and Political Weekly* 45:43–54

Samuelson PA (1954) The pure theory of public expenditure. *Review of Economics and Statistics* 36:387–389

Starkie D (2002) Airport regulation and competition. *Journal of Air Transport Management* 8:63–72

Staw BM (1976) Knee-deep in the big muddy: A study of escalating commitment to a chosen course of action. *Organizational Behavior and Human Performance* 16:27–44

Williamson OE (1985) The economic institutions of capitalism. Free Press

Media reports cited for 2026 developments

Note: No official government order, AAI master plan or pre-feasibility report on the 2026 decisions below had been published when this paper was written. These reports are cited only

to document the announcements that define Scenario P0. They should be replaced with the corresponding official documents, such as Tamil Nadu Legislative Assembly proceedings, government orders, or AAI's pre-feasibility report and master plan, once these are available.

Business Standard (2026) 150-km radius rule loses relevance once airport capacity saturates: Naidu. 4 January

Business Today (2026) Assembly elections 2026: Will Kolkata, Chennai airport privatisation be back on the table? 5 May

DT Next (2026) Terminal 5 to be satellite facility for Chennai airport: Director. 13 June

Free Press Journal (2026) Vijay govt moves on new Chennai airport after Parandur setback; Manellore, Cheyyur shortlisted. September

Republic World (2026) Tamil Nadu shortlists Cheyyur, Gummidipoondi sites for Chennai's second airport; AAI asked to conduct pre-feasibility study. 6 September

The News Minute (2026) AAI approves public road link for Chennai airport's upcoming satellite terminal. 15 June

ETV Bharat (2026) Vijay says Parandur airport will come up at alternative site; Stalin slams 'irreversible setback' for Tamil Nadu. 24 August

The Week (2026) Why TN govt dropped Parandur airport project? CM Vijay says new site to be proposed. 24 August

Appendix: Proofs

A.1 Lemma 1 and Proposition 1

The derivation proceeds in six steps.

Step 1 (composite output). Define the composite effort–investment index

$$Y \equiv e^{\alpha_1} I^{\alpha_2}, \qquad \text{so that } \Pi_O = B\,Y - \frac{e^2}{2} - c\,I.$$

Step 2 (first-order condition for effort). Differentiating with respect to e,

$$\frac{\partial \Pi_O}{\partial e} = \alpha_1 B\, e^{\alpha_1 - 1} I^{\alpha_2} - e = 0.$$

Because $e^{\alpha_1 - 1} I^{\alpha_2} = Y/e$, this is

$$e = \frac{\alpha_1 BY}{e} \quad \Rightarrow \quad e^2 = \alpha_1 BY \quad \Rightarrow \quad e = (\alpha_1 BY)^{1/2}.$$

Step 3 (first-order condition for investment). Differentiating with respect to I,

$$\frac{\partial \Pi_O}{\partial I} = \alpha_2 B\, e^{\alpha_1} I^{\alpha_2 - 1} - c = 0.$$

Because $e^{\alpha_1} I^{\alpha_2 - 1} = Y/I$, this is

$$c = \frac{\alpha_2 BY}{I} \quad \Rightarrow \quad I = \frac{\alpha_2 BY}{c}.$$

Step 4 (substitute both conditions into the definition of Y). Inserting Steps 2 and 3 into Step 1,

$$Y = e^{\alpha_1} I^{\alpha_2} = (\alpha_1 BY)^{\alpha_1/2} \left(\frac{\alpha_2 BY}{c}\right)^{\alpha_2} = Y^{\alpha_1/2+\alpha_2} (\alpha_1 B)^{\alpha_1/2} \left(\frac{\alpha_2 B}{c}\right)^{\alpha_2}.$$

Step 5 (collect powers of Y and define σ). Dividing both sides by $Y^{\alpha_1/2+\alpha_2}$,

$$Y^{\,1-\alpha_1/2-\alpha_2} = (\alpha_1 B)^{\alpha_1/2} \left(\frac{\alpha_2 B}{c}\right)^{\alpha_2}.$$

The exponent on the left is the returns-to-scale wedge, $\sigma \equiv 1 - \alpha_1/2 - \alpha_2$. The factor $\alpha_1/2$ appears because effort enters Y with elasticity α_1 but, from Step 2, effort scales with the square root of Y. Provided $\sigma > 0$,

$$Y^* = \left[(\alpha_1 B)^{\alpha_1/2} \left(\frac{\alpha_2 B}{c}\right)^{\alpha_2}\right]^{1/\sigma},$$

and $e^* = (\alpha_1 BY^*)^{1/2}$ and $I^* = \alpha_2 BY^*/c$ follow from Steps 2 and 3. This is (5).

Step 6 (profit and second-order conditions). Substituting $e^{*2}/2 = \alpha_1 BY^*/2$ and $cI^* = \alpha_2 BY^*$ into Π_O gives $\Pi_O^* = BY^* - 1/2\,\alpha_1 BY^* - \alpha_2 BY^* = \sigma BY^*$. At the stationary point, $\Pi_{ee} = \alpha_1 - 2 < 0$, $\Pi_{II} = -\alpha_2(1-\alpha_2)BY/I^2$ and $\Pi_{eI} = \alpha_1\alpha_2 BY/(eI)$. The Hessian determinant is $\Pi_{ee}\Pi_{II} - \Pi_{eI}^2 = (\alpha_2 BY/I^2)\,[(2-\alpha_1)(1-\alpha_2) - \alpha_1\alpha_2] = (\alpha_2 BY/I^2)\cdot 2\sigma$. It is positive iff $\sigma > 0$, so the stationary point is the unique maximum. The same $\sigma > 0$ condition therefore guarantees both existence of the closed form and concavity.

Comparative statics (Proposition 1). Since $Y^* \propto B^{(\alpha_1/2+\alpha_2)/\sigma} c^{-\alpha_2/\sigma}$, Y^* increases in B and decreases in c. Then $e^* = (\alpha_1 BY^*)^{1/2}$ and $I^* = \alpha_2 BY^*/c$ inherit the signs. B increases in A and m_L and decreases in t and $\overline{\theta}$. Its derivative with respect to π is $-\left(1 - e^{-\overline{\theta}} m_L\right) < 0$. Finally, $c = 1 - \rho_O s$ decreases in s and in ρ_O (for $s > 0$). ■

The closed form was verified numerically: for $B = 1.7$, $\alpha_1 = 0.3$, $\alpha_2 = 0.6$, $s = 0.2$ and $\rho_O = 0.9$, direct numerical maximisation returns $(e, I, \Pi) = (0.7582, 1.4022, 0.47909)$, identical to (5) to four decimal places.

A.2 Proposition 2

With complete contracts, write $W = D\{\Pi_O + [k(1-\psi) + (1+\lambda)tr]\overline{Q} - (1+\lambda)\rho_G sI\} +$ const. This is (7) regrouped using $\Pi_O = (1-t)r\overline{Q} - e^2/2 - (1-\rho_O s)I$. By the envelope theorem applied to (4), $d\Pi_O/ds = \rho_O I^*$. Differentiating the remaining terms gives (8). At $s = s^b$, if $s^b < 0$ the last term of (8) is positive and the transfer term reduces to λI^*. Hence $dW/ds > 0$ whenever $[k(1-\psi) + (1+\lambda)tr]\, d\overline{Q}/ds > \lambda I^* + (1+\lambda)s\, dI^*/ds$, which holds for k and t large relative to λ. Since $d\overline{Q}/ds > 0$ by Proposition 1, $s^* > s^b$. ■

A.3 Proposition 3

Let $\Delta W(\chi,\psi) = \max_I W^H(I;\chi) - \max_s W^P(s;\psi)$. By the envelope theorem, $\partial \max_I W^H / \partial \chi = D^H[k + (1+\lambda)r]\ \partial Q^H / \partial \chi > 0$, since A_{mH} is linear in χ and Q^H increases in A_{mH} both directly and through e^H. Also $\partial \max_s W^P / \partial \psi = -D\ k\ \overline{Q} < 0$. Hence ΔW increases in both χ and ψ. The zero contour $\chi^*(\psi)$ exists by continuity (given limits where each mode dominates) and slopes downward: $d\chi^*/d\psi = -(\partial \Delta W / \partial \psi)/(\partial \Delta W / \partial \chi) < 0$. Renegotiation costs, arrears and a shorter in-house delay each raise ΔW at a given χ, which lowers χ^*. ■

A.4 Proposition 4

Maximising $\beta \ln(V_O + T - O_O) + (1-\beta)\ln(V_G - (1+\lambda)T - O_G)$ gives $\beta/u_O = (1-\beta)(1+\lambda)/u_G$, where u_O and u_G are the two surpluses. Summing $u_G + (1+\lambda)u_O = \Sigma$ yields $u_O = \beta\Sigma/(1+\lambda)$ and hence (10). Part (i): the operator's payoff $O_O + \beta\Sigma/(1+\lambda)$ depends on its own continuation value only through Σ, with weight β. If disagreement payoffs do not depend on throughput, the marginal return to throughput is scaled by β. Part (ii): expected rents from renegotiation, $\pi(1-q)\beta\Sigma/(1+\lambda)$, raise the left-hand side of (6) at every s and increase in β, so the smallest s that satisfies (6) falls. Part (iii): a higher β affects welfare through three channels. (a) It lowers s^b (part ii), which reduces I^* and Y^* by Proposition 1; under the condition of Proposition 2 ($dW/ds > 0$ at s^b), this lowers welfare. (b) It raises the expected transfer, whose shadow cost λT^* enters Λ_m. (c) It raises $m_L = (1-q)\beta + q(1-\delta)$, which strengthens low-state incentives. Welfare falls in β whenever (a) and (b) outweigh (c). This holds throughout the calibrated range: welfare falls from 4.14 to 3.66 as β rises from 0.1 to 0.9 (Fig. 3b). ■

A.5 Proposition 6

With a binding floor, low-state revenue is $\overline{R}\,(1-t)rAY$ irrespective of effort, so $m_L = 0$ in (3). The expected payout is $\pi \max\{0,\ \overline{R}(1-t)rAY - (1-t)rAe^{-\overline{\theta}}Y\}$, which gives (11). It is piecewise linear in $\overline{R}$ with a kink at $e^{-\overline{\theta}}$, and it increases in π and $\overline{\theta}$. ■

A.6 Proposition 7

For $s > 0$, the operator values the grant at $\rho_O sI$ and the state pays $\rho_G sI$. The difference $(\rho_G - \rho_O)sI > 0$ appears with a negative sign in (7), since $-(1+\lambda)\rho_G sI + \rho_O sI = -\lambda\rho_G sI - (\rho_G - \rho_O)sI$. Because $\sigma B Y^*(s)$ increases in $\rho_O s$ only through the product $\rho_O s$, a fall in ρ_O (a rise in τ) must be offset by a proportional rise in s to keep (6) binding: $s^b = \overline{\zeta}/\rho_O$ for a constant $\overline{\zeta}$. Hence $\partial s^b / \partial \tau = i_O\, s^b > 0$. ■

A.7 Proposition 8

Let $a(\mu) = i_G H_m e^{-\gamma(\mu-1)}$. The discount factor $f(\mu) = e^{-i_G \Delta^G_m} \exp[-a(\mu)]$ has $f' = \gamma a f > 0$ and $f'' = \gamma^2 a f\,(a-1)$, so f is concave wherever $a(\mu) < 1$, that is, wherever the hold-out delay discount exponent is below one. This holds in the calibration ($a \le 0.38$ at $\mu = 2$). The objective $f(\mu)\widetilde{W}_m - (1+\lambda)\mu V_m$ is then strictly concave, and its first-order condition is (12). The left-hand side of (12) increases in $\widetilde{W}_m$ and H_m, so μ^* increases in both. If the left-hand side at $\mu = 2$ falls short of $(1+\lambda)V_m$, the floor binds. The value lost per year of delay is the congestion cost the greenfield would have relieved. An alternative that relieves congestion during the delay, such as

Terminal 5, lowers the value at stake in early opening, which enters (12) through $\widetilde{W}_m$. It therefore lowers μ^*. ■

A.8 Proposition 9

(i) AAI's payoff difference equals the discounted revenue on traffic served by T5 that would otherwise have been spilled or diverted, less its cost. This difference is positive under the calibration (₹37,553 crore against ₹36,220 crore). (ii) Terminal 5 raises K_t^A and delays the dates at which spill costs arise, which lowers the marginal benefit of an early greenfield. (iii) Opening before saturation places a share w of demand at the greenfield, which adds access cost without reducing spill, while bringing forward capital expenditure. Hence the cost-minimising opening is weakly after the date at which spill becomes material, which is close to saturation. (iv) Follows from comparing (14) across strategies. The numerical equilibrium is reported in Tables 5–6. ■