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Bargaining for Toll Adjustment during General Purpose Lane Maintenance and Resulting Congestion

: A Repeated Game Approach

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Table of Contents

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Background

The U.S. State Department of Transportations (DOT) face constraints in closing general-purpose lanes to implement scheduled/unanticipated maintenance

- One of the key reasons is that the outages of road facilities incur large Road User Cost (RUC)

Literature suggests various mitigation strategies

- Increasing the awareness of users help change their behaviors in the face of lanes outage (Brown, Taylor, and Wachs, 2016, p. 291)
- The extension of nearby facilities by converting shoulders to lanes lessen impacts on users (Zhu, Levinson, Liu, and Harder, 2010, p. 782)

Increasing access to adjacent managed lanes can be one policy option (Gifford, Manganaris, and Gao, 2021, p. 1)

- State DOTs could cooperate with adjacent toll operators to use some capacity of toll roads during downtime
- It has long-term benefits to both parties; DOTs reduce RUC burdens, and toll operators can launch more travelers to the downtime vacant facilities

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Compensation Issues in Downtime Toll Suspension

For the governments to use toll facilities, compensation is unavoidable

- By reducing or suspending toll during downtime, toll operators incur profit loss
- Most P3 agreements give state DOTs the right to suspend the toll from the managed lanes
- Toll operators are endowed right to claim compensation for profit loss due to the government action

Existing P3 practices suggest post-contract bargaining of the compensations

- P3 Comprehensive Development Agreements (CDAs) do have terms such as 'department changes', 'significant force majeure events,' or 'unavailability events with pre-determined price'
- However, the contracts do not specify ex-ante clarifications such as compensation calculation guidelines on the terms

(Research Question) Will it be beneficial for state DOTs and concessionaires to have ex-ante contingency compensation terms rather than after-contract bargaining options?

- The theory of incomplete contracts suggest that a near-complete contingency plan is impossible to draft ex-ante (Hart and Moore, 1988, p. 755)
- Ex-ante probabilistic uncertainty consideration will at least partially enable it (Maskin and Tirole, 1999, p. 106; Javed, Lam, and Chan, 2014, p.324)

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* Existing Contracts Review: P3 Project Cases

[Table 1] The P3 Contracts Reviewed

State	Project	Managed Lane Type	Contract Award Year
North Carolina	I-77	Express Toll lanes	2014
Texas	Lyndon B. Johnson IH-635 Managed Lanes	Express Toll lanes	2009
	North Tarrant Expressway	Express Toll lanes	2009
	SH-288 Harris County	Toll lanes	2016
Virginia	I-495 Express Lanes	Express Toll lanes	2007
	I-95 Express Lanes	HOV/HOT	2012
	Transform 66	Express Toll lanes	2016
	I-95 Fredericksburg Extension ("Fredex")	Express Toll lanes	2019

- Reviewed Comprehensive Development Agreements (CDAs) to find possible compensation options

- The selection criteria
  - U.S. managed lane P3 contracts
  - There is/are adjacent general-purpose lanes and managed lanes
  - Dallas Fort Worth (DFW) Connector Project was reviewed but excluded as the CDA does not include relevant terms

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* Existing Contracts Review: P3 Project Cases

Study Points

1. Does the CDA grant the state department of transportation (DOT) the right to suspend tolls?
2. Under what circumstances does the CDA allow state-required toll suspension without providing financial compensation for the concessionaire?
3. Does the CDA explicitly mention compensation events linked to revenue losses or financial i mbalances caused by state DoT decisions?
4. Which CDA mechanisms could address toll revenue losses caused by changes implemented in support of planned or unplanned maintenance on public-sector facilities?
5. If the state DOT and concessionaire cannot agree on a compensation event, which institution or body is responsible for solving the dispute?

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* Existing Contracts Review: P3 Project Cases

[Table 2] The Existence of Potential Toll Suspension Terms in the CDAs

Questions (unless otherwise written, responses are coded as YES=1 and 0=NO)	I-77	SH-288 Harris County	IH-635 Managed Lanes	North Tarrant Expressway	DFW Connector Project	Transform 66	I-495 Express Lanes	I-95 Express Lanes	I-95 (Fredex)
1. Does the Comprehensive Agreement (CA) grant to DoT the right to require toll suspension?	1	1	1	1	0	1	1	1	1
2. Under what circumstances is DoT allowed to require toll suspension without giving rise to a financial compensation to the developer?									
2.1 Emergency mass evacuation route	1	1	1	1	NA	1	1	1	1
2.2 Other emergency use, as declared by Governmental Authorities	1	1	1	1	NA	1		1	1
2.3 Diversion of traffic due to significant incidents that closes lanes on GP lanes	0	0	0	0	NA	1	1	1	1
2.4 Diversion of traffic due to significant incidents that closes lanes on another state highways	0	0	0	0	NA	1	1	1	1
2.5 Diversion of traffic due to a significant incident, with casualties requiring hospitalization or fatalities on GP lanes	0	0	0	0	NA	1	1	1	1
2.6 Diversion of traffic due to a significant incident, with casualties requiring hospitalization or fatalities on another state highways	0	0	0	0	NA	1	1	1	1
2.7 Diversion of traffic due to federal government request for national security and homeland security purposes	0	0	0	0	NA	1	0	0	1
3. Are compensation events related to loss of revenues or financial imbalance caused by DoT decisions explicitly mentioned in the CA?	1	1	1	1	NA	1	1	1	1
4. Under the CA, which mechanisms could be used to address a loss of toll revenues due to planned or unplanned maintenance?									
4.1 Department changes (potentially generating a compensation event)	1	1	1	1	NA	1	1	1	1
4.2 Significant force majeure event	0	0	0	0	NA	1	0	1	0
4.3 Occurrence of a Significant Reserved Rights event within or immediately adjacent to the Express Lanes (potentially generating a compensation event)	0	0	0	0	NA	1	1	0	0
4.4 Unavailability event (with prices pre-determined in the contract)	1	0	0	0	NA	0	0	0	0
5. If DoT and the Developer are unable to agree upon a compensation event, which body is responsible for solving the dispute? (Numbers represent sequential order from the first to the last stage of dispute resolution; 0 indicates that this body does not have a role in dispute resolution)									
5.1 Steering Committee	0	0	0	0	NA	1	0	1	1
5.2 Local circuit court	2	3	3	3	NA	3	2	2	3
5.3 Independent Engineer	0	0	0	0	NA	0	1	0	0
5.4 Mediator	1	1	1	1	NA	2	0	0	2
5.5 Dispute board	0	2	2	2	NA	0	0	0	0

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* Existing Contracts Review: P3 Project Cases

Qualitative Findings

CDAs include terms on the toll road suspension right of state DOTs

- Some have **direct terms** on the suspension right for a general lane closure
- The others not: '**other emergency use**' of Government Authorities applicable

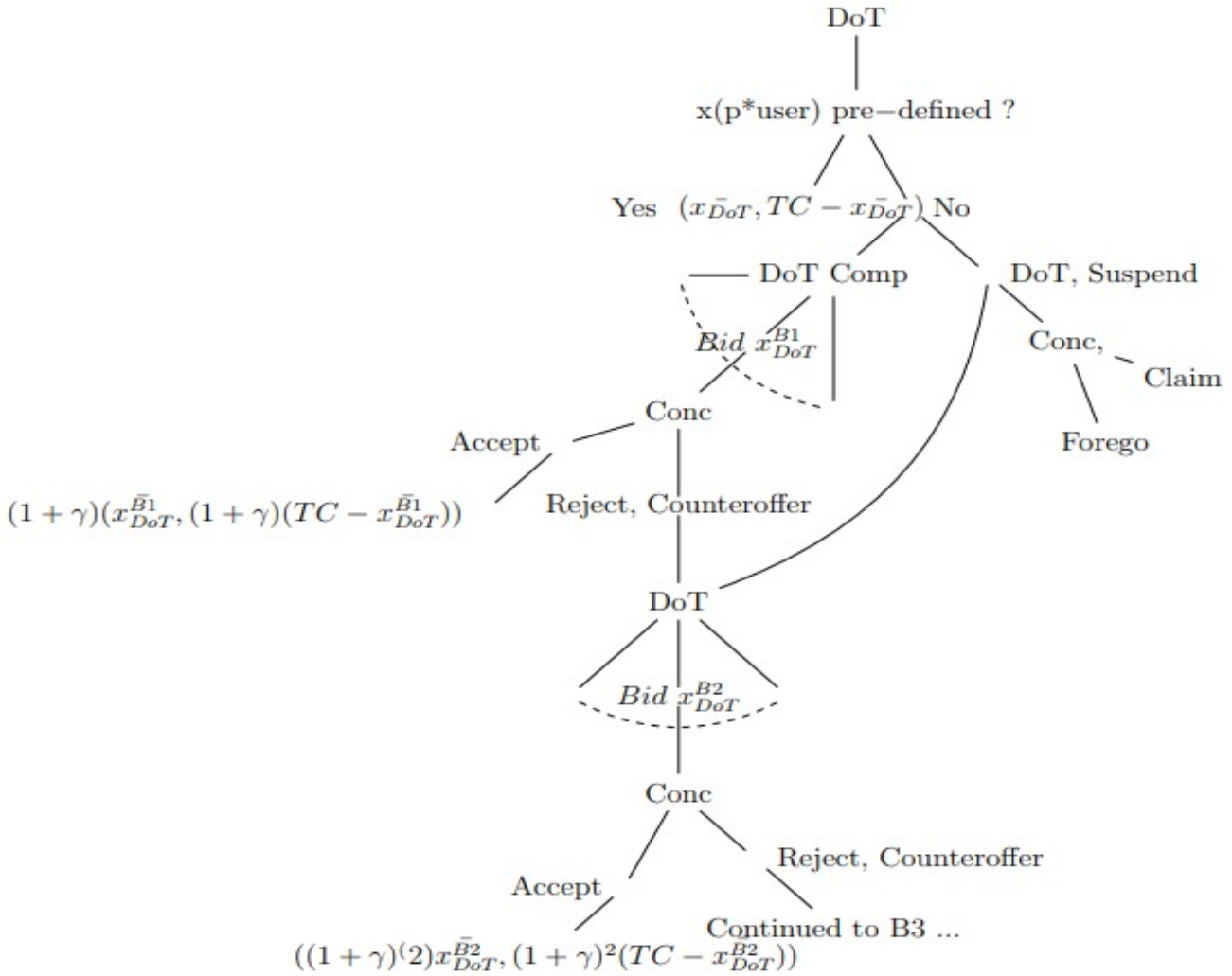
Compensation Event in the DoT caused loss / financial imbalance are specified

- All contracts specify '**department changes**' as available mechanisms
- Others: **significant force majeure event / adjacent Significant Reserved Rights event / unavailability event with a pre-determined price**

Mediator and Steering Committee are preferred for dispute from unsettled compensation event

- Court, dispute boards are considered as second options

The Model



[Figure 1] The Extensive Form Visualization of the Compensation Bargaining Game

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The Model: The Players and Incentives

Player 1: A State Department of Transportation (DOT)

The public entity has greater power in maintenance and compensation choices including the forced suspension of tolls.

- Road User Cost (RUC) **(+)**
- Actual maintenance cost **(+)**
- Transaction cost for the compensation bargaining **(+)**
  - consulting, accounting, workforce utilization, etc.
- Time delay in the compensation agreement **(+)**

Player 2: A Toll Concessionaire

The private/other public concessionaire has a right to claim all expected profit losses induced by DOT

The direct profit loss (current profit + expected future profit**)** **(+)**

- Transaction cost for the compensation bargaining **(+)**
  - consulting, accounting, workforce utilization, etc.
- Information cost **(-)**
- The long-term relationship with the State DOT **(-)**

Both players solve cost minimization problems.

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The Model: Assumptions (A Simplest Case)

- The maintenance duration and lanes are exogenously determined
  - The operational features are given and reflected as a lumpsum cost at t = 0
  - State DOTs' expectations on compensations are already reflected in the set maintenance schedule
- The toll price during maintenance reduces to zero (toll holiday)
  - We start from the binary pricing case of 0 or full P
  - In reality, any pricing is possible within the continuum of 0 to full P
- There is only one type of user (homogeneous users)
  - In reality, different users react differently to the road maintenance and toll price
- There is a fixed time-discount factor for each player
  - In reality, time cost will be different for each bargaining time, not only for each player

Later, some extensions will be done by removing or weakening the assumptions.

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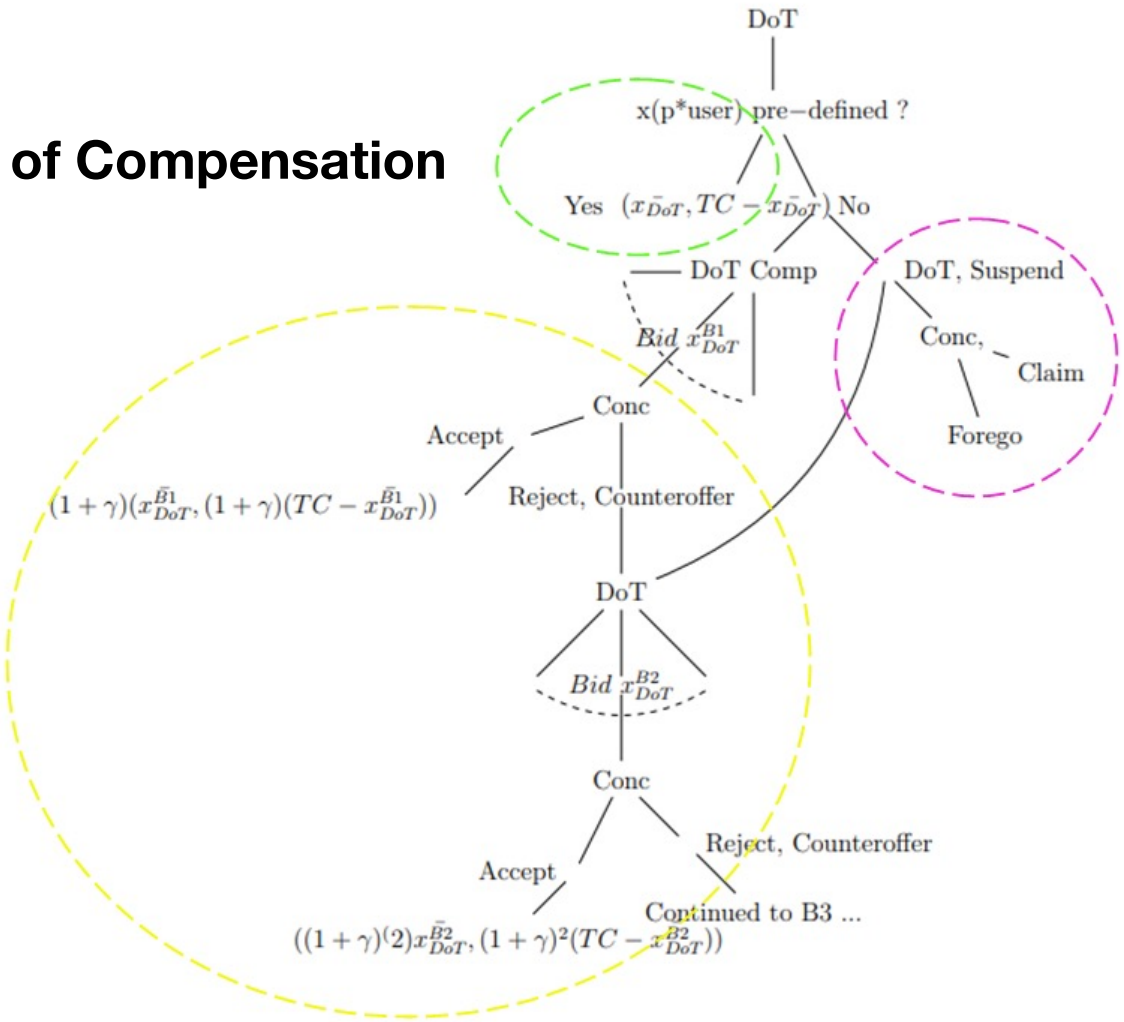
The Model: The Subgames of Compensation



[Figure 2] The Three Subgames of the Compensation Bargaining Game

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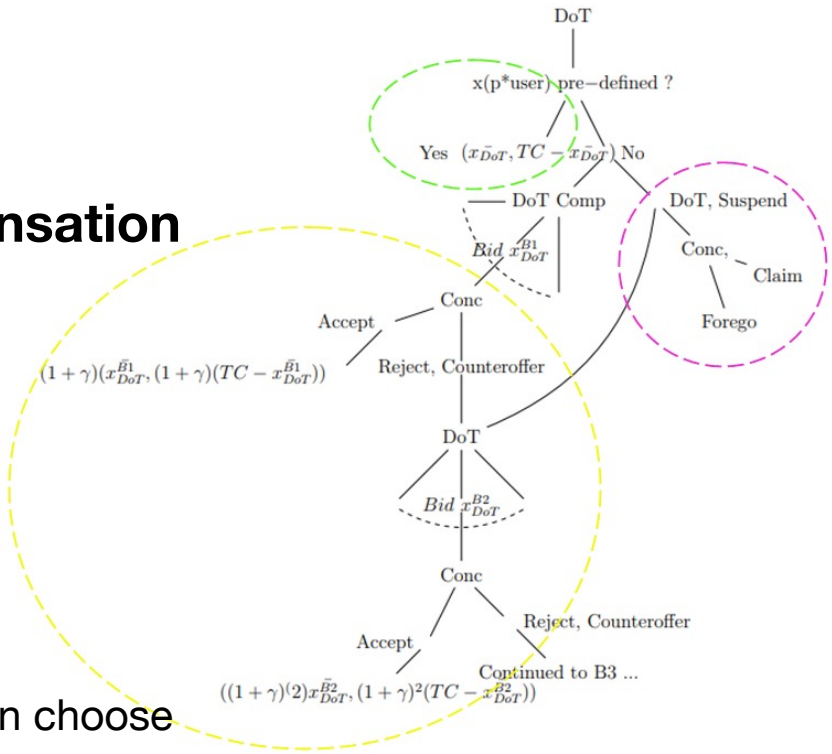
The Model: The Subgames of Compensation



Subgame 1: The ex-ante compensation case

If both parties agree ex-ante to a claim amount 'x' or the calculation mechanism, the compensation follows the term and game ends.

Subgame 2: DOT forced toll suspension case

If forced toll suspension happens, toll operator can choose to claim or forgo the compensation

(Forgo if information cost + long-term relationship > direct cost + transaction cost)

Subgame 3: The ex-post compensation bargaining case

DOT and the toll operator repeatedly bid the compensation amount until the other accepts. Each bidding step delays the agreement and incurs time costs to both parties.

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Anticipated Equilibrium

Stochastic Time Cost Increment Case

1) Bargaining subgame analysis

Players: State DOT (Player 1), Concessionaire (Player 2)

Rounds: Infinite time-horizon with stages t={0, 1, 2, …}

Total Cost for Renegotiation: Stochastic incrementing function $z^{t+1} = (1+\rho)z^t + \varepsilon_{t+1}$,

$$where \quad \rho \in (0,1), \quad \mathbb{E}(\varepsilon_{t+1}|z^t) = 0, \quad Prob(\varepsilon_{t+1} \leq -(1+\rho)z^t|z^t) = 0$$

- At the beginning of stage t, the players observe the value of z^t, but not future values z^{t+1}, …
- In even-numbered stage {0, 2, 4, 6, …}, state DOT offer compensation $x^t \in (0, z^t)$ and concessionaire {accept, reject}.
- In odd-numbered stage {1, 3, 5, 7, …}, concessionaire offer compensation $x^t \in (0, z^t)$ and state DOT {accept, reject}.
- The game begins in stage 0, and ends the first time an offer is accepted.
- Players have time-fixed discount factors $\delta_1, \delta_2 \in (0,1)$ and perceived cost increases at $(1+\delta_1), (1+\delta_2)$ each.
- If an offer is accepted at t, state DOT pays $(1+\delta_1)^t x^t$, and concessionaire pays $(1+\delta_2)^t (z^t - x^t)$.

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Anticipated Equilibrium

Stochastic Time Cost Increment Case

1) Bargaining subgame analysis

1. Analysis of the Total Cost

$$\mathbb{E}(z^{t+1}|z^t) = (1+\rho)z^t + \mathbb{E}(\varepsilon_{t+1}|z^t) = (1+\rho)z^t$$

2. Feasibility

For SPNEs with a stationary solution to exist, the solution of all accepted offers should be in the feasibility set.

$$z^t \le (1+\delta_i)\mathbb{E}(z^{t+1}) = (1+\delta_i)(1+\rho)z^t \quad (true)$$

3. Best Responses

In t, if player 2 (concessionaire) rejects $x_1^*(z^t)$, expected payoff(cost incurred) in t+1 is $(1+\delta_2)^{t+1}(\mathbb{E}(z^{t+1}) - x_2^*(z^{t\prime}))$.
Therefore, player 2's best response is to accept if $(1+\delta_2)^t(z^t - x_1^*(z^t)) \le (1+\delta_2)^{t+1}\ (\mathbb{E}(z^{t+1}) - x_2^*(z^{t\prime}))$ (and reject else.)

∴ Player 1 needs to offer $x_1^*(z^t) = z^t - (1+\delta_2) \quad (\mathbb{E}(z^{t+1}) - x_2^*(z^{t\prime}))$.

Equally, if player 1 (state DOT) rejects $x_2^*(z^{t\prime})$, expected payoff(cost incurred) in t'+1 is $(1+\delta_1)^{t\prime+1}x_1^*(z^t))$.
Therefore, player 1's best response is to accept if $(1+\delta_1)^{t\prime}x_2^*(z^{t\prime}) \le (1+\delta_1)^{t\prime+1}x_1^*(z^t))$.

∴ Player 2 needs to offer $x_2^*(z^{t\prime}) = (1+\delta_1)\ \ x_1^*(z^t))$.

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Anticipated Equilibrium

Stochastic Time Cost Increment Case

1) Bargaining subgame analysis

4. Solutions and Payoffs (cost)

$$x_1^*(z^t) = z^t - (1+\delta_2)^{\square}\,(\mathbb{E}(z^{t+1}) - x_2^*(z^{t'}))$$

$$x_2^*(z^{t'}) = (1+\delta_1)^{\square} x_1^*(z^t))$$

$$x_1^* = \frac{((1+\delta_2)(1+\rho)-1)z^0}{(1+\delta_1)(1+\delta_2)-1} \qquad f_D^R = (1+\delta_1)^t x_{\square}^*,$$

$$x_2^* = \frac{(1+\delta_1)((1+\delta_2)(1+\rho)-1)z^0}{(1+\delta_1)(1+\delta_2)-1}, \quad f_C^R = (1+\delta_2)^t(\mathbb{E}(z^{t+1}) - x_{\square}^*)$$

δ_1, δ_2 = **individual cost from renegotiation delay**

ρ = **overall cost increase by delay (user, etc)**

$z^0 = TC_{\square}^R\ \mathbb{E}(z^{t+1}) = (1+\rho)^t z^0$

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Anticipated Equilibrium

Stochastic Time Cost Increment Case

2) The three subgames equilibrium

- Subgame 1: $\left(\overline{x_1},\ z^0 - \overline{x_1}\right)$
- Subgame 2: $\left(0,\ z^0\right),\ the\ suspension - forgo\ case$
- Subgame 3: $\left(\frac{\left((1+\delta_2)(1+\rho)-1\right)z^0}{(1+\delta_1)(1+\delta_2)-1},\ \frac{(1+\delta_1)\left((1+\delta_2)(1+\rho)-1\right)z^0}{(1+\delta_1)(1+\delta_2)-1}\right)$, where $\delta_1, \delta_2, \rho \in (0,1)$

$\therefore$ Pareto optimal point: $\left(\overline{x_1},\ z^0 - \overline{x_1}\right)$

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Anticipated Equilibrium

- The ex-ante contingency compensation agreement is anticipated to be Pareto optimal in all Subgame Perfect Nash Equilibrium points.
  - The time cost of repeated bargaining will incur a higher cost to both parties
  - The subgame of toll suspension / claim or forgo will incur the highest cost to the toll operator
  - Ideally, including all possible contingencies predictable and designing a concrete compensation function will
    - Reduce the time cost for bargaining to both parties
    - Keep sustainable public-private partnership by avoiding the forced suspension incidence
    - DOTs will better plan maintenance events
    - Private concessionaires can better account for uncertainties at the contract drafting/signing

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Thank you !

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