# Supplementary Material

**Resolving transboundary water conflicts: Evolutionary analysis using an improved GMCR model**

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**Table S1**

Solution concepts and the relevant behavior and important features

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Solution concept** | **Definitions** | **Foresight** | **Disimprovement** | **Knowledge of preferences** | **Strategic risk** |
| Nash stability | Inability of the focal decision maker to move to a more preferred state unilaterally | Low  (1 move) | Never | Own | Ignores risk |
| General MetaRationality (GMR) | All decision makers unilateral advances are sanctioned by other decision makers’ subsequent unilateral moves | Medium  (2 move) | By opponents | Own | Avoids risk; conservative |
| Symmetric Metarationality (SMR) | All decision makers unilateral advances are still sanctioned even after a possible response by the focal decision maker to sanctioning | Medium  (3 move) | By opponents | Own | Avoids risk; conservative |
| Sequential Stability (SEQ) | ALL of the decision makers unilateral improvements are sanctioned by further unilateral advances of other decision makers | Medium  (2 move) | Never | All | Takes some risks; satisfices |

Note: Solution concepts in GMCR. Adapted from Fang et al. (1993), Kilgour and Hipel (2005), Taravatrooy et al. (2019).

**Table S2**

Evolution of the conflict states

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DMs** | **Option numbers** | **Strategy** | **Status quo** | | **Transitional states** | | | **Equilibrium state** | |
| **S1** |  | **S3** |  | **S6** |  | **S12** |
| JS | 1 | Maintain | Y |  | Y |  |  |  |  |
| 2 | Strengthen |  |  |  |  | Y |  | Y |
| SH & ZJ | 3 | Compel | Y |  | Y |  | Y |  |  |
| 4 | Share |  |  |  |  |  |  | Y |
| TBA | 5 | Persuade | Y |  |  |  |  |  |  |
| 6 | Award |  |  |  |  |  |  |  |
| 7 | Punish |  |  | Y |  | Y |  | Y |

**Table S3**

Preference rankings of DMs and results of stability analysis in different size of P

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Class** | **Different size of P** | **DMs** | **Benefits rankings** | **Preference rankings** | **Scenario** | **Stable state** |
| **Ⅰ** | **P ≥ C > S** | JS | 0 > A+S-C > S-C > A-C > -C ≥ -P | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | **s1\*** | **S12** |
| SH & ZJ | D > A+D-S > D-S > D-P ≥ 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > (~) S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -C ≥ -P | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s2 |
| SH & ZJ | D > A+D-S > D-S > D-P ≥ 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > (~) S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > A-C > -C ≥ -P | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s3 |
| SH & ZJ | D > A+D-S > D-S > 0 > D-P ≥ A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S6 > (~) S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -C ≥ -P | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s4 |
| SH & ZJ | D > A+D-S > D-S > 0 > D-P ≥ A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S6 > (~) S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > A-C > -C ≥ -P | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s5 |
| SH & ZJ | D > A+D-S > D-S > 0 > A-S > D-P ≥ -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S8 > S6 > (~) S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -C ≥ -P | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s6 |
| SH & ZJ | D > A+D-S > D-S > 0 > A-S > D-P ≥ -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S8 > S6 > (~) S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > A-C > -C ≥ -P | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s7 |
| SH & ZJ | D > A+D-S > D-S > 0 > A-S > -S > D-P > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S8 > S7 ~ S9 > S6 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -C ≥ -P | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S4 ~ S6 > (~) S3 ~ S9 | s8 |
| SH & ZJ | D > A+D-S > D-S > 0 > A-S > -S > D-P > -P | S4 ~ S5 > S11 > S10 ~ S12 > S1 ~ S2 > S8 > S7 ~ S9 > S6 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| **Ⅱ** | **C > P > S; P > C - S** | JS | 0 > A+S-C > S-C > A-C > -P > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | **s9\*** | **S12** |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > -P ≥ A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s10 |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -P > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | s11 |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > -P ≥ A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s12 |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| **Ⅲ** | **C > P > S; P ≤ C - S** | JS | 0 > A+S-C > -P ≥ S-C > A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S3 ~ S9 > (~) S10 ~ S12 > S5 > S4 ~ S6 | **s13\*** | **S9** |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > -P ≥ S-C > A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S3 ~ S9 > (~) S10 ~ S12 > S5 > S4 ~ S6 | s14 |
| SH & ZJ | D > A+D-S > D-S > D-P > 0 > A-S > -S > -P | S4 ~ S5 > S11 > S10 ~ S12 > S6 > S1 ~ S2 > S8 > S7 ~ S9 > S3 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| **Ⅳ** | **S ≥ P > 0** | JS | 0 > A+S-C > S-C > A-C > -P > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | **s15\*** | **None** |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > -P ≥ A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s16 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -P > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | s17 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > -P ≥ A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s18 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > -P ≥ S-C > A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S3 ~ S9 > (~) S10 ~ S12 > S5 > S4 ~ S6 | s19 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > -P ≥ S-C > A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S3 ~ S9 >(~) S10 ~ S12 > S5 > S4 ~ S6 | s20 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > A-S > -P ≥ -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S8 > S3 > (~) S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > A-C > -P > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | s21 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > S-C > -P ≥ A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s22 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > A-C > -P > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S5 > S3 ~ S9 > S4 ~ S6 | s23 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > S-C > -P ≥ A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S10 ~ S12 > S3 ~ S9 > (~) S5 > S4 ~ S6 | s24 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | 0 > A+S-C > -P ≥ S-C > A-C > -C | S1 ~ S2 ~ S7 ~ S8 > S11 > S3 ~ S9 > (~) S10 ~ S12 > S5 > S4 ~ S6 | s25 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |
| JS | A+S-C ≥ 0 > -P ≥ S-C > A-C > -C | S11 > (~) S1 ~ S2 ~ S7 ~ S8 > S3 ~ S9 >(~) S10 ~ S12 > S5 > S4 ~ S6 | s26 |
| SH & ZJ | D > A+D-S > D-P > D-S > 0 > -P ≥ A-S > -S | S4 ~ S5 > S11 > S6 > S10 ~ S12 > S1 ~ S2 > S3 > (~) S8 > S7 ~ S9 |
| TBA | B1+B2 > B1+B2-2A > B1+P > B1 > B1-A > B2+P > B2 > B2-A > 2P > 0 | S10 ~ S12 > S11 > S6 > S4 > S5 > S9 > S7 > S8 > S3 > S1 ~ S2 |

Note: “\*” represents that Scenarios 1, 9, 13, and 15 were shown in Table 6 as the specific examples.

# References

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