**F1. Robust optimization mathematics**

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| --- | --- |
| $$Min E[z\_{1}]=z\_{1}+η1Icap\_{i}PO\_{hi}\left(ρ2\_{i}\_{\left(4\right)}-ρ2\_{i}\_{\left(3\right)}\left(1-α1\right)-ρ2\_{i}\_{\left(4\right)}α1\right)$$ | Eq. (F1.1) |
| $+η2Icap\_{r}RO\_{hr}\left(ρ3\_{r}\_{\left(4\right)}-ρ3\_{r}\_{\left(3\right)}\left(1-β\right)-ρ3\_{r}\_{\left(4\right)}β\right)$ $$+ η3\left(Dem\_{p\left(4\right)}^{t}-Dem\_{p\left(4\right)}^{t}\left(1-α2\right)-Dem\_{p\left(3\right)}^{t}α2\right)$$ |  |
| $$+η4\left(Dem\_{pw\left(4\right)}^{t}-Dem\_{pw\left(4\right)}^{t}\left(1-α3\right)-Dem\_{pw\left(3\right)}^{t}α3\right)$$ |  |
| $$Min E[z\_{2}]+ ξ(z\_{2\left(max\right)}- E[z\_{2}])+η'1Icap\_{i}PO\_{hi}\left(ρ2\_{i}\_{\left(4\right)}-ρ2\_{i}\_{\left(3\right)}\left(1-α1\right)-ρ2\_{i}\_{\left(4\right)}α1\right)+ $$ | Eq. (F1.2) |
| $$η'2Icap\_{r}RO\_{hr}\left(ρ3\_{r}\_{\left(4\right)}-ρ3\_{r}\_{\left(3\right)}\left(1-β\right)-ρ3\_{r}\_{\left(4\right)}β\right)+ $$ |  |
| $$η'3\left(Dem\_{p\left(4\right)}^{t}-Dem\_{p\left(4\right)}^{t}\left(1-α2\right)-Dem\_{p\left(3\right)}^{t}α2\right)$$ |  |
| $$+η'4\left(Dem\_{pw\left(4\right)}^{t}-Dem\_{pw\left(4\right)}^{t}\left(1-α3\right)-Dem\_{pw\left(3\right)}^{t}α3\right)$$ |  |
| $$Min E[z\_{3}]+ ξ(z\_{3\left(max\right)}- E[z\_{3}])+η''1Icap\_{i}PO\_{hi}\left(ρ2\_{i}\_{\left(4\right)}-ρ2\_{i}\_{\left(3\right)}\left(1-α1\right)-ρ2\_{i}\_{\left(4\right)}α1\right)+$$ | Eq. (F1.3) |
| $$η''2Icap\_{r}RO\_{hr}\left(ρ3\_{r}\_{\left(4\right)}-ρ3\_{r}\_{\left(3\right)}\left(1-β\right)-ρ3\_{r}\_{\left(4\right)}β\right)$$ |  |
| $$+ η''3\left(Dem\_{p\left(4\right)}^{t}-Dem\_{p\left(4\right)}^{t}\left(1-α2\right)-Dem\_{p\left(3\right)}^{t}α2\right)$$ |  |
| $$+η''4\left(Dem\_{pw\left(4\right)}^{t}-Dem\_{pw\left(4\right)}^{t}\left(1-α3\right)-Dem\_{pw\left(3\right)}^{t}α3\right)$$ |  |
| $$Inv\_{pit}+Dem\_{p\left(4\right)}^{t}\left(1-α2\right)+Dem\_{p\left(3\right)}^{t}α2-Inv\_{pit-1}+b\_{pit-1}= X\_{pit} + b\_{pit}$$ | Eq. (F1.4) |
| $$\sum\_{p}^{}Inv\_{pit} AX\_{iw}VUN\_{p}\leq Icap\_{i}PO\_{hi}(ρ2\_{i}\_{\left(3\right)}\left(1-α1\right)+ρ2\_{i}\_{\left(4\right)}α1)$$ | Eq. (F1.5) |
| $$\sum\_{w}^{}\sum\_{i}^{}\sum\_{p}^{}Inv\_{pit} BX\_{wr}VUN\_{1p}\leq Icap\_{r}RO\_{hr}(ρ3\_{r}\_{\left(3\right)}\left(1-β\right)+ρ3\_{r}\_{\left(4\right)}β)$$ | Eq. (F1.6) |
| $$\sum\_{w}^{}(Dem\_{pw\left(4\right)}^{t}\left(1-α3\right)+Dem\_{pw\left(3\right)}^{t}α3)AX\_{iw}\leq X\_{pit}$$ | Eq. (F1.7) |
| $$\sum\_{w}^{}\sum\_{v}^{}LAO\_{wuv}^{t}-\sum\_{p}^{}Dem\_{pu\left(4\right)}^{t}\left(1-α3\right)+Dem\_{pu\left(3\right)}^{t}α3=\sum\_{w}^{}\sum\_{v}^{}LAO\_{uwv}^{t}$$ | Eq. (F1.8) |
| $$\sum\_{p}^{}\sum\_{u}^{}(Dem\_{pu\left(4\right)}^{t}\left(1-α3\right)+Dem\_{pu\left(3\right)}^{t}α3)Rout\_{wuv}^{t}\leq \sum\_{u}^{}(1-Rout\_{wuv}^{t}) BN+LAO\_{wuv}^{t}$$ | Eq. (F1.9) |
| $${(\sum\_{i}^{}b\_{pit}}/{(Dem\_{p\left(4\right)}^{t}\left(1-α2\right)+Dem\_{p\left(3\right)}^{t}α2))} Woc\_{p}\leq 1- αs$$ | Eq. (F1.10) |
| $$0.5\leq α1,α2,α3,β\leq 1$$ | Eq. (F1.11) |

**F2. Features of test problems**

Features of small-sized and large-sized test problems (t=10).

|  |  |  |
| --- | --- | --- |
|  | Small-sized (S1-S10) | Large-sized (L1-L10) |
| $$\left|h\right|$$ | 5 | 7 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 30 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 80 | 90 |
| $$\left|s\right|$$ | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 8 |
| $$\left|i\right|$$ | 4 | 4 | 4 | 6 | 7 | 8 | 9 | 10 | 15 | 18 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| $$\left|r\right|$$ | 2 | 2 | 2 | 3 | 4 | 4 | 5 | 5 | 6 | 7 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 50 | 55 |
| $$\left|w\right|$$ | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 12 | 12 | 16 | 35 | 45 | 45 | 55 | 55 | 65 | 65 | 75 | 85 | 100 |
| $$\left|p\right|$$ | 2 | 2 | 3 | 3 | 4 | 4 | 6 | 6 | 8 | 10 | 12 | 12 | 13 | 15 | 20 | 20 | 25 | 25 | 30 | 30 |
| $$\left|v\right|$$ | 3 | 5 | 3 | 7 | 7 | 8 | 8 | 9 | 13 | 13 | 15 | 20 | 30 | 35 | 45 | 55 | 65 | 70 | 75 | 80 |