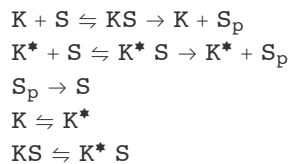


# Bistable motif: parameter sampling

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## Finding the condition of multistationarity

We consider the following reactions:



The species of the system are:



In total, there are 11 reactions and 6 species.

We firstly construct the ordinary differential equations based on mass-action kinetics. Then compute the determinant of Jacobian, using the solution at critical point (steady state) to calculate the determinant. The (necessary) condition for multistationarity is to make determinant equal to zero (non-zero determinant implies injectivity).

```

A = Table[0, {11}, {6}];
A[[1]][[1]] = -1;
A[[1]][[3]] = -1;
A[[1]][[5]] = 1;
A[[2]] = -A[[1]];
A[[3]][[3]] = 1; A[[3]][[2]] = 1; A[[3]][[5]] = -1;
A[[4]][[1]] = -1;
A[[4]][[4]] = -1;
A[[4]][[6]] = 1;
A[[5]] = -A[[4]];
A[[6]][[4]] = 1;
A[[6]][[2]] = 1;
A[[6]][[6]] = -1;
A[[7]][[2]] = -1;
A[[7]][[1]] = 1;
A[[8]][[3]] = -1; A[[8]][[4]] = 1; A[[9]] = -A[[8]];
A[[10]][[5]] = -1; A[[10]][[6]] = 1; A[[11]] = -A[[10]];
stoiM = Transpose[A];
(* Now we construct the rate vector *)
ks = {k1 × x3 × x1, k2 × x5, k3 × x5, k4 × x4 × x1,
      k5 × x6, k6 × x6, k7 × x2, k8 × x3, k9 × x4, k10 × x5, k11 × x6};
ssEqns = stoiM.ks;
mC = RowReduce[NullSpace[A]];
subsEqns = {ssEqns[[2]], ssEqns[[4]],
            ssEqns[[5]], ssEqns[[6]], x1 + x2 + x5 + x6 - T1, x3 + x4 + x5 + x6 - T2};
jacobian = D[subsEqns, {{x1, x2, x3, x4, x5, x6}}];
detJ = Collect[Distribute[Det[jacobian]], {x1, x2, x3, x4, x5, x6});
solution =
  Solve[{subsEqns[[1]], subsEqns[[2]], subsEqns[[3]], subsEqns[[4]] == 0},
        {x2, x4, x5, x6});
detSubs = Replace[detJ, solution[[1]], {0, Infinity}];
(* Equivilant to detSubs=detJ/.solution[[1]]; *)
polSubs = Numerator[Together[detSubs]];
finalSubs = Collect[Distribute[polSubs], x_, FactorTerms]

-k22 k52 k7 k8 k9 - 2 k2 k3 k52 k7 k8 k9 - k32 k52 k7 k8 k9 - 2 k22 k5 k6 k7 k8 k9 - 4 k2 k3 k5 k6 k7 k8 k9 -
2 k32 k5 k6 k7 k8 k9 - k22 k62 k7 k8 k9 - 2 k2 k3 k62 k7 k8 k9 - k32 k62 k7 k8 k9 - k22 k52 k7 k92 -
2 k2 k3 k52 k7 k92 - k32 k52 k7 k92 - 2 k22 k5 k6 k7 k92 - 4 k2 k3 k5 k6 k7 k92 - 2 k32 k5 k6 k7 k92 -
k22 k62 k7 k92 - 2 k2 k3 k62 k7 k92 - k32 k62 k7 k92 - 2 k2 k52 k7 k8 k9 k10 - 2 k3 k52 k7 k8 k9 k10 -
4 k2 k5 k6 k7 k8 k9 k10 - 4 k3 k5 k6 k7 k8 k9 k10 - 2 k2 k62 k7 k8 k9 k10 - 2 k3 k62 k7 k8 k9 k10 -
2 k2 k52 k7 k92 k10 - 2 k3 k52 k7 k92 k10 - 4 k2 k5 k6 k7 k92 k10 - 4 k3 k5 k6 k7 k92 k10 - 2 k2 k62 k7 k92 k10 -
2 k3 k62 k7 k92 k10 - k52 k7 k8 k9 k102 - 2 k5 k6 k7 k8 k9 k102 - k62 k7 k8 k9 k102 - k52 k7 k92 k102 -
2 k5 k6 k7 k92 k102 - k62 k7 k92 k102 - 2 k22 k5 k7 k8 k9 k11 - 4 k2 k3 k5 k7 k8 k9 k11 - 2 k32 k5 k7 k8 k9 k11 -
2 k22 k6 k7 k8 k9 k11 - 4 k2 k3 k6 k7 k8 k9 k11 - 2 k32 k6 k7 k8 k9 k11 - 2 k22 k5 k7 k92 k11 -
4 k2 k3 k5 k7 k92 k11 - 2 k32 k5 k7 k92 k11 - 2 k22 k6 k7 k92 k11 - 4 k2 k3 k6 k7 k92 k11 - 2 k32 k6 k7 k92 k11 -
2 k2 k5 k7 k8 k9 k10 k11 - 2 k3 k5 k7 k8 k9 k10 k11 - 2 k2 k6 k7 k8 k9 k10 k11 - 2 k3 k6 k7 k8 k9 k10 k11 -
2 k2 k5 k7 k92 k10 k11 - 2 k3 k5 k7 k92 k10 k11 - 2 k2 k6 k7 k92 k10 k11 - 2 k3 k6 k7 k92 k10 k11 -
k22 k7 k8 k9 k112 - 2 k2 k3 k7 k8 k9 k112 - k32 k7 k8 k9 k112 - k22 k7 k92 k112 - 2 k2 k3 k7 k92 k112 -
k32 k7 k92 k112 + (-k1 k2 k42 k7 k10 k11 - k1 k3 k42 k7 k10 k11 - k1 k2 k42 k7 k112 - k1 k3 k42 k7 k112) x13 +
(-k22 k4 k5 k6 k82 - 2 k2 k3 k4 k5 k6 k82 - k32 k4 k5 k6 k82 - k22 k4 k62 k82 - 2 k2 k3 k4 k62 k82 - k32 k4 k62 k82 -
k22 k4 k5 k7 k82 - 2 k2 k3 k4 k5 k7 k82 - k32 k4 k5 k7 k82 - k22 k4 k6 k7 k82 - 2 k2 k3 k4 k6 k7 k82 -
k32 k4 k6 k7 k82 - k1 k2 k3 k52 k8 k9 - k1 k32 k52 k8 k9 - 2 k1 k2 k3 k5 k6 k8 k9 - 2 k1 k32 k5 k6 k8 k9 -
k22 k4 k5 k6 k8 k9 - 2 k2 k3 k4 k5 k6 k8 k9 - k32 k4 k5 k6 k8 k9 - k1 k2 k3 k62 k8 k9 -
k1 k32 k62 k8 k9 - k22 k4 k62 k8 k9 - 2 k2 k3 k4 k62 k8 k9 - k32 k4 k62 k8 k9 - k22 k4 k5 k7 k8 k9 -
2 k2 k3 k4 k5 k7 k8 k9 - k32 k4 k5 k7 k8 k9 - k1 k2 k52 k7 k8 k9 - k1 k3 k52 k7 k8 k9 -
k22 k4 k6 k7 k8 k9 - 2 k2 k3 k4 k6 k7 k8 k9 - k32 k4 k6 k7 k8 k9 - 2 k1 k2 k5 k6 k7 k8 k9 -
2 k1 k3 k5 k6 k7 k8 k9 - k1 k2 k62 k7 k8 k9 - k1 k3 k62 k7 k8 k9 - k1 k2 k3 k52 k92 - k1 k32 k52 k92 -
2 k1 k2 k3 k5 k6 k92 - 2 k1 k32 k5 k6 k92 - k1 k2 k3 k62 k92 - k1 k32 k62 k92 - k1 k2 k52 k7 k92 -

```

$$\begin{aligned}
& k_1 k_3 k_5^2 k_7 k_9^2 - 2 k_1 k_2 k_5 k_6 k_7 k_9^2 - 2 k_1 k_3 k_5 k_6 k_7 k_9^2 - k_1 k_2 k_6^2 k_7 k_9^2 - k_1 k_3 k_6^2 k_7 k_9^2 - \\
& 2 k_2 k_4 k_5 k_6 k_8^2 k_{10} - 2 k_3 k_4 k_5 k_6 k_8^2 k_{10} - 2 k_2 k_4 k_6^2 k_8^2 k_{10} - 2 k_3 k_4 k_6^2 k_8^2 k_{10} - \\
& 2 k_2 k_4 k_5 k_7 k_8^2 k_{10} - 2 k_3 k_4 k_5 k_7 k_8^2 k_{10} - 2 k_2 k_4 k_6 k_7 k_8^2 k_{10} - 2 k_3 k_4 k_6 k_7 k_8^2 k_{10} - \\
& k_1 k_3 k_5^2 k_8 k_9 k_{10} - k_1 k_2 k_5 k_6 k_8 k_9 k_{10} - 3 k_1 k_3 k_5 k_6 k_8 k_9 k_{10} - 2 k_2 k_4 k_5 k_6 k_8 k_9 k_{10} - \\
& 2 k_3 k_4 k_5 k_6 k_8 k_9 k_{10} - k_1 k_2 k_6^2 k_8 k_9 k_{10} - 2 k_1 k_3 k_6^2 k_8 k_9 k_{10} - 2 k_2 k_4 k_6^2 k_8 k_9 k_{10} - \\
& 2 k_3 k_4 k_6^2 k_8 k_9 k_{10} - k_1 k_2 k_5 k_7 k_8 k_9 k_{10} - k_1 k_3 k_5 k_7 k_8 k_9 k_{10} - 2 k_2 k_4 k_5 k_7 k_8 k_9 k_{10} - \\
& 2 k_3 k_4 k_5 k_7 k_8 k_9 k_{10} - k_1 k_5^2 k_7 k_8 k_9 k_{10} - k_1 k_2 k_6 k_7 k_8 k_9 k_{10} - k_1 k_3 k_6 k_7 k_8 k_9 k_{10} - \\
& 2 k_2 k_4 k_6 k_7 k_8 k_9 k_{10} - 2 k_3 k_4 k_6 k_7 k_8 k_9 k_{10} - 2 k_1 k_5 k_6 k_7 k_8 k_9 k_{10} - k_1 k_6^2 k_7 k_8 k_9 k_{10} - \\
& k_1 k_3 k_5^2 k_9^2 k_{10} - k_1 k_2 k_5 k_6 k_9^2 k_{10} - 3 k_1 k_3 k_5 k_6 k_9^2 k_{10} - k_1 k_2 k_6^2 k_9^2 k_{10} - 2 k_1 k_3 k_6^2 k_9^2 k_{10} - \\
& k_1 k_2 k_5 k_7 k_9^2 k_{10} - k_1 k_3 k_5 k_7 k_9^2 k_{10} - k_1 k_5^2 k_7 k_9^2 k_{10} - k_1 k_2 k_6 k_7 k_9^2 k_{10} - k_1 k_3 k_6 k_7 k_9^2 k_{10} - \\
& 2 k_1 k_5 k_6 k_7 k_9^2 k_{10} - k_1 k_6^2 k_7 k_9^2 k_{10} - k_4 k_5 k_6 k_8^2 k_{10}^2 - k_4 k_6^2 k_8^2 k_{10}^2 - k_4 k_5 k_7 k_8^2 k_{10}^2 - \\
& k_4 k_6 k_7 k_8^2 k_{10}^2 - k_1 k_5 k_6 k_8 k_9 k_{10}^2 - k_4 k_5 k_6 k_8 k_9 k_{10}^2 - k_1 k_6^2 k_8 k_9 k_{10}^2 - k_4 k_6^2 k_8 k_9 k_{10}^2 - \\
& k_1 k_5 k_7 k_8 k_9 k_{10}^2 - k_4 k_5 k_7 k_8 k_9 k_{10}^2 - k_1 k_6 k_7 k_8 k_9 k_{10}^2 - k_4 k_6 k_7 k_8 k_9 k_{10}^2 - \\
& k_1 k_5 k_6 k_9^2 k_{10}^2 - k_1 k_6^2 k_9^2 k_{10}^2 - k_1 k_5 k_7 k_9^2 k_{10}^2 - k_1 k_6 k_7 k_9^2 k_{10}^2 - k_2 k_3 k_4 k_5 k_8^2 k_{11} - \\
& k_3^2 k_4 k_5 k_8^2 k_{11} - k_2^2 k_4 k_6 k_8^2 k_{11} - 3 k_2 k_3 k_4 k_6 k_8^2 k_{11} - 2 k_3^2 k_4 k_6 k_8^2 k_{11} - k_2^2 k_4 k_7 k_8^2 k_{11} - \\
& 2 k_2 k_3 k_4 k_7 k_8^2 k_{11} - k_3^2 k_4 k_7 k_8^2 k_{11} - k_2 k_4 k_5 k_7 k_8^2 k_{11} - k_3 k_4 k_5 k_7 k_8^2 k_{11} - \\
& k_2 k_4 k_6 k_7 k_8^2 k_{11} - k_3 k_4 k_6 k_7 k_8^2 k_{11} - 2 k_1 k_2 k_3 k_5 k_8 k_9 k_{11} - 2 k_1 k_3^2 k_5 k_8 k_9 k_{11} - \\
& k_2 k_3 k_4 k_5 k_8 k_9 k_{11} - k_3^2 k_4 k_5 k_8 k_9 k_{11} - 2 k_1 k_2 k_3 k_6 k_8 k_9 k_{11} - 2 k_1 k_3^2 k_6 k_8 k_9 k_{11} - \\
& k_2^2 k_4 k_6 k_8 k_9 k_{11} - 3 k_2 k_3 k_4 k_6 k_8 k_9 k_{11} - 2 k_3^2 k_4 k_6 k_8 k_9 k_{11} - k_2^2 k_4 k_7 k_8 k_9 k_{11} - \\
& 2 k_2 k_3 k_4 k_7 k_8 k_9 k_{11} - k_3^2 k_4 k_7 k_8 k_9 k_{11} - 2 k_1 k_2 k_5 k_7 k_8 k_9 k_{11} - 2 k_1 k_3 k_5 k_7 k_8 k_9 k_{11} - \\
& k_2 k_4 k_5 k_7 k_8 k_9 k_{11} - k_3 k_4 k_5 k_7 k_8 k_9 k_{11} - 2 k_1 k_2 k_6 k_7 k_8 k_9 k_{11} - 2 k_1 k_3 k_6 k_7 k_8 k_9 k_{11} - \\
& k_2 k_4 k_6 k_7 k_8 k_9 k_{11} - k_3 k_4 k_6 k_7 k_8 k_9 k_{11} - 2 k_1 k_2 k_3 k_5 k_9^2 k_{11} - 2 k_1 k_3^2 k_5 k_9^2 k_{11} - \\
& 2 k_1 k_2 k_3 k_6 k_9^2 k_{11} - 2 k_1 k_3^2 k_6 k_9^2 k_{11} - 2 k_1 k_2 k_5 k_7 k_9^2 k_{11} - 2 k_1 k_3 k_5 k_7 k_9^2 k_{11} - \\
& 2 k_1 k_2 k_6 k_7 k_9^2 k_{11} - 2 k_1 k_3 k_6 k_7 k_9^2 k_{11} - k_3 k_4 k_5 k_8^2 k_{10} k_{11} - k_2 k_4 k_6 k_8^2 k_{10} k_{11} - \\
& 2 k_3 k_4 k_6 k_8^2 k_{10} k_{11} - k_2 k_4 k_7 k_8^2 k_{10} k_{11} - k_3 k_4 k_7 k_8^2 k_{10} k_{11} - k_4 k_5 k_7 k_8^2 k_{10} k_{11} - \\
& k_4 k_6 k_7 k_8^2 k_{10} k_{11} - k_1 k_3 k_5 k_8 k_9 k_{10} k_{11} - k_3 k_4 k_5 k_8 k_9 k_{10} k_{11} - k_1 k_2 k_6 k_8 k_9 k_{10} k_{11} - \\
& 2 k_1 k_3 k_6 k_8 k_9 k_{10} k_{11} - k_2 k_4 k_6 k_8 k_9 k_{10} k_{11} - 2 k_3 k_4 k_6 k_8 k_9 k_{10} k_{11} - \\
& k_1 k_2 k_7 k_8 k_9 k_{10} k_{11} - k_1 k_3 k_7 k_8 k_9 k_{10} k_{11} - k_2 k_4 k_7 k_8 k_9 k_{10} k_{11} - k_3 k_4 k_7 k_8 k_9 k_{10} k_{11} - \\
& k_1 k_5 k_7 k_8 k_9 k_{10} k_{11} - k_4 k_5 k_7 k_8 k_9 k_{10} k_{11} - k_1 k_6 k_7 k_8 k_9 k_{10} k_{11} - k_4 k_6 k_7 k_8 k_9 k_{10} k_{11} - \\
& k_1 k_3 k_5 k_9^2 k_{10} k_{11} - k_1 k_2 k_6 k_9^2 k_{10} k_{11} - 2 k_1 k_3 k_6 k_9^2 k_{10} k_{11} - k_1 k_2 k_7 k_9^2 k_{10} k_{11} - \\
& k_1 k_3 k_7 k_9^2 k_{10} k_{11} - k_1 k_5 k_7 k_9^2 k_{10} k_{11} - k_1 k_6 k_7 k_9^2 k_{10} k_{11} - k_2 k_3 k_4 k_8^2 k_{11}^2 - \\
& k_3^2 k_4 k_8^2 k_{11}^2 - k_2 k_4 k_7 k_8^2 k_{11}^2 - k_3 k_4 k_7 k_8^2 k_{11}^2 - k_1 k_2 k_3 k_8 k_9 k_{11}^2 - k_1 k_3^2 k_8 k_9 k_{11}^2 - \\
& k_2 k_3 k_4 k_8 k_9 k_{11}^2 - k_3^2 k_4 k_8 k_9 k_{11}^2 - k_1 k_2 k_7 k_8 k_9 k_{11}^2 - k_1 k_3 k_7 k_8 k_9 k_{11}^2 - k_2 k_4 k_7 k_8 k_9 k_{11}^2 - \\
& k_3 k_4 k_7 k_8 k_9 k_{11}^2 - k_1 k_2 k_3 k_9^2 k_{11}^2 - k_1 k_3^2 k_9^2 k_{11}^2 - k_1 k_2 k_7 k_9^2 k_{11}^2 - k_1 k_3 k_7 k_9^2 k_{11}^2) x_3 + \\
& x_1^2 (-k_1 k_2 k_4 k_5 k_7 k_9 k_{10} - k_1 k_3 k_4 k_5 k_7 k_9 k_{10} - k_1 k_2 k_4 k_6 k_7 k_9 k_{10} - k_1 k_3 k_4 k_6 k_7 k_9 k_{10} - \\
& k_1 k_4 k_5 k_7 k_9 k_{10}^2 - k_1 k_4 k_6 k_7 k_9 k_{10}^2 - k_2^2 k_4^2 k_7 k_8 k_{11} - 2 k_2 k_3 k_4^2 k_7 k_8 k_{11} - \\
& k_3^2 k_4^2 k_7 k_8 k_{11} - 2 k_1 k_2 k_4 k_5 k_7 k_9 k_{11} - 2 k_1 k_3 k_4 k_5 k_7 k_9 k_{11} - 2 k_1 k_2 k_4 k_6 k_7 k_9 k_{11} - \\
& 2 k_1 k_3 k_4 k_6 k_7 k_9 k_{11} - k_1 k_2 k_4 k_5 k_7 k_{10} k_{11} - k_1 k_3 k_4 k_5 k_7 k_{10} k_{11} - \\
& k_1 k_2 k_4 k_6 k_7 k_{10} k_{11} - k_1 k_3 k_4 k_6 k_7 k_{10} k_{11} - k_2 k_4^2 k_7 k_8 k_{10} k_{11} - k_3 k_4^2 k_7 k_8 k_{10} k_{11} - \\
& 2 k_1 k_2 k_4 k_7 k_9 k_{10} k_{11} - 2 k_1 k_3 k_4 k_7 k_9 k_{10} k_{11} - k_1 k_4 k_5 k_7 k_9 k_{10} k_{11} - \\
& k_1 k_4 k_6 k_7 k_9 k_{10} k_{11} - k_2^2 k_4^2 k_7 k_{11}^2 - 2 k_2 k_3 k_4^2 k_7 k_{11}^2 - k_3^2 k_4^2 k_7 k_{11}^2 - \\
& k_2 k_4^2 k_7 k_8 k_{11}^2 - k_3 k_4^2 k_7 k_8 k_{11}^2 - 2 k_1 k_2 k_4 k_7 k_9 k_{11}^2 - 2 k_1 k_3 k_4 k_7 k_9 k_{11}^2 + \\
& (k_1^2 k_3 k_4 k_5 k_9 k_{10} + k_1^2 k_3 k_4 k_6 k_9 k_{10} - k_1^2 k_4 k_5 k_6 k_9 k_{10} - k_1^2 k_4 k_6^2 k_9 k_{10} - k_1^2 k_4 k_5 k_6 k_{10}^2 - \\
& k_1^2 k_4 k_6^2 k_{10}^2 - k_1^2 k_4 k_5 k_7 k_{10}^2 - k_1^2 k_4 k_6 k_7 k_{10}^2 - k_1 k_2 k_3 k_4^2 k_8 k_{11} - k_1 k_3^2 k_4^2 k_8 k_{11} + k_1 k_2 \\
& k_4^2 k_6 k_8 k_{11} + k_1 k_3 k_4^2 k_6 k_8 k_{11} - k_1^2 k_3 k_4 k_5 k_{10} k_{11} - k_1^2 k_3 k_4 k_6 k_{10} k_{11} - k_1 k_2 k_4^2 k_6 k_{10} \\
& k_{11} - k_1 k_3 k_4^2 k_6 k_{10} k_{11} - k_1 k_2 k_4^2 k_7 k_{10} k_{11} - k_1 k_3 k_4^2 k_7 k_{10} k_{11} - k_1^2 k_4 k_5 k_7 k_{10} k_{11} - \\
& k_1^2 k_4 k_6 k_7 k_{10} k_{11} - k_1 k_2 k_3 k_4^2 k_{11}^2 - k_1 k_3^2 k_4^2 k_{11}^2 - k_1 k_2 k_4^2 k_7 k_{11}^2 - k_1 k_3 k_4^2 k_7 k_{11}^2) x_3) + \\
& x_1 (-k_2^2 k_4 k_5 k_7 k_8 k_9 - 2 k_2 k_3 k_4 k_5 k_7 k_8 k_9 - k_3^2 k_4 k_5 k_7 k_8 k_9 - k_2^2 k_4 k_6 k_7 k_8 k_9 - \\
& 2 k_2 k_3 k_4 k_6 k_7 k_8 k_9 - k_3^2 k_4 k_6 k_7 k_8 k_9 - k_1 k_2 k_5^2 k_7 k_9^2 - k_1 k_3 k_5^2 k_7 k_9^2 - \\
& 2 k_1 k_2 k_5 k_6 k_7 k_9^2 - 2 k_1 k_3 k_5 k_6 k_7 k_9^2 - k_1 k_2 k_6^2 k_7 k_9^2 - k_1 k_3 k_6^2 k_7 k_9^2 - k_1 k_2 k_5^2 k_7 k_9 k_{10} - \\
& k_1 k_3 k_5^2 k_7 k_9 k_{10} - 2 k_1 k_2 k_5 k_6 k_7 k_9 k_{10} - 2 k_1 k_3 k_5 k_6 k_7 k_9 k_{10} - k_1 k_2 k_6^2 k_7 k_9 k_{10} - \\
& k_1 k_3 k_6^2 k_7 k_9 k_{10} - 2 k_2 k_4 k_5 k_7 k_8 k_9 k_{10} - 2 k_3 k_4 k_5 k_7 k_8 k_9 k_{10} - 2 k_2 k_4 k_6 k_7 k_8 k_9 k_{10} - \\
& 2 k_3 k_4 k_6 k_7 k_8 k_9 k_{10} - k_1 k_2 k_5 k_7 k_9^2 k_{10} - k_1 k_3 k_5 k_7 k_9^2 k_{10} - k_1 k_5^2 k_7 k_9^2 k_{10} - \\
& k_1 k_2 k_6 k_7 k_9^2 k_{10} - k_1 k_3 k_6 k_7 k_9^2 k_{10} - 2 k_1 k_5 k_6 k_7 k_9^2 k_{10} - k_1 k_6^2 k_7 k_9^2 k_{10} - k_1 k_5^2 k_7 k_9 k_{10}^2 - \\
& 2 k_1 k_5 k_6 k_7 k_9 k_{10}^2 - k_1 k_6^2 k_7 k_9 k_{10}^2 - k_4 k_5 k_7 k_8 k_9 k_{10}^2 - k_4 k_6 k_7 k_8 k_9 k_{10}^2 - \\
& k_1 k_5 k_7 k_9^2 k_{10}^2 - k_1 k_6 k_7 k_9^2 k_{10}^2 - k_2^2 k_4 k_5 k_7 k_8 k_{11} - 2 k_2 k_3 k_4 k_5 k_7 k_8 k_{11} -
\end{aligned}$$

$$\begin{aligned}
& k_3^2 k_4 k_5 k_7 k_8 k_{11} - k_2^2 k_4 k_6 k_7 k_8 k_{11} - 2 k_2 k_3 k_4 k_6 k_7 k_8 k_{11} - k_3^2 k_4 k_6 k_7 k_8 k_{11} - \\
& 2 k_2^2 k_4 k_5 k_7 k_9 k_{11} - 4 k_2 k_3 k_4 k_5 k_7 k_9 k_{11} - 2 k_3^2 k_4 k_5 k_7 k_9 k_{11} - 2 k_2^2 k_4 k_6 k_7 k_9 k_{11} - \\
& 4 k_2 k_3 k_4 k_6 k_7 k_9 k_{11} - 2 k_3^2 k_4 k_6 k_7 k_9 k_{11} - k_2^2 k_4 k_7 k_8 k_9 k_{11} - 2 k_2 k_3 k_4 k_7 k_8 k_9 k_{11} - \\
& k_3^2 k_4 k_7 k_8 k_9 k_{11} - k_2 k_4 k_5 k_7 k_8 k_9 k_{11} - k_3 k_4 k_5 k_7 k_8 k_9 k_{11} - k_2 k_4 k_6 k_7 k_8 k_9 k_{11} - \\
& k_3 k_4 k_6 k_7 k_8 k_9 k_{11} - 2 k_1 k_2 k_5 k_7 k_9^2 k_{11} - 2 k_1 k_3 k_5 k_7 k_9^2 k_{11} - 2 k_1 k_2 k_6 k_7 k_9^2 k_{11} - \\
& 2 k_1 k_3 k_6 k_7 k_9^2 k_{11} - k_2 k_4 k_5 k_7 k_8 k_{10} k_{11} - k_3 k_4 k_5 k_7 k_8 k_{10} k_{11} - k_2 k_4 k_6 k_7 k_8 k_{10} k_{11} - \\
& k_3 k_4 k_6 k_7 k_8 k_{10} k_{11} - k_1 k_2 k_5 k_7 k_9 k_{10} k_{11} - k_1 k_3 k_5 k_7 k_9 k_{10} k_{11} - 2 k_2 k_4 k_5 k_7 k_9 k_{10} k_{11} - \\
& 2 k_3 k_4 k_5 k_7 k_9 k_{10} k_{11} - k_1 k_2 k_6 k_7 k_9 k_{10} k_{11} - k_1 k_3 k_6 k_7 k_9 k_{10} k_{11} - \\
& 2 k_2 k_4 k_6 k_7 k_9 k_{10} k_{11} - 2 k_3 k_4 k_6 k_7 k_9 k_{10} k_{11} - k_2 k_4 k_7 k_8 k_9 k_{10} k_{11} - \\
& k_3 k_4 k_7 k_8 k_9 k_{10} k_{11} - k_4 k_5 k_7 k_8 k_9 k_{10} k_{11} - k_4 k_6 k_7 k_8 k_9 k_{10} k_{11} - k_1 k_2 k_7 k_9^2 k_{10} k_{11} - \\
& k_1 k_3 k_7 k_9^2 k_{10} k_{11} - k_1 k_5 k_7 k_9^2 k_{10} k_{11} - k_1 k_6 k_7 k_9^2 k_{10} k_{11} - k_2^2 k_4 k_7 k_8 k_{11}^2 - \\
& 2 k_2 k_3 k_4 k_7 k_8 k_{11}^2 - k_3^2 k_4 k_7 k_8 k_{11}^2 - 2 k_2^2 k_4 k_7 k_9 k_{11}^2 - 4 k_2 k_3 k_4 k_7 k_9 k_{11}^2 - \\
& 2 k_3^2 k_4 k_7 k_9 k_{11}^2 - k_2 k_4 k_7 k_8 k_9 k_{11}^2 - k_3 k_4 k_7 k_8 k_9 k_{11}^2 - k_1 k_2 k_7 k_9^2 k_{11}^2 - k_1 k_3 k_7 k_9^2 k_{11}^2 - \\
& 2 \left( k_1 k_2 k_4 k_5 k_6 k_8 k_{10} + k_1 k_3 k_4 k_5 k_6 k_8 k_{10} + k_1 k_2 k_4 k_6^2 k_8 k_{10} + k_1 k_3 k_4 k_6^2 k_8 k_{10} + \right. \\
& k_1 k_2 k_4 k_5 k_7 k_8 k_{10} + k_1 k_3 k_4 k_5 k_7 k_8 k_{10} + k_1 k_2 k_4 k_6 k_7 k_8 k_{10} + k_1 k_3 k_4 k_6 k_7 k_8 k_{10} + \\
& k_1 k_2 k_4 k_5 k_6 k_9 k_{10} + k_1 k_3 k_4 k_5 k_6 k_9 k_{10} + k_1 k_2 k_4 k_6^2 k_9 k_{10} + k_1 k_3 k_4 k_6^2 k_9 k_{10} + \\
& k_1 k_2 k_4 k_5 k_7 k_9 k_{10} + k_1 k_3 k_4 k_5 k_7 k_9 k_{10} + k_1 k_2 k_4 k_6 k_7 k_9 k_{10} + k_1 k_3 k_4 k_6 k_7 k_9 k_{10} + \\
& k_1 k_4 k_5 k_6 k_8 k_{10}^2 + k_1 k_4 k_6^2 k_8 k_{10}^2 + k_1 k_4 k_5 k_7 k_8 k_{10}^2 + k_1 k_4 k_6 k_7 k_8 k_{10}^2 + \\
& k_1 k_4 k_5 k_6 k_9 k_{10}^2 + k_1 k_4 k_6^2 k_9 k_{10}^2 + k_1 k_4 k_5 k_7 k_9 k_{10}^2 + k_1 k_4 k_6 k_7 k_9 k_{10}^2 + \\
& k_1 k_2 k_3 k_4 k_5 k_8 k_{11} + k_1 k_3^2 k_4 k_5 k_8 k_{11} + k_1 k_2 k_3 k_4 k_6 k_8 k_{11} + k_1 k_3^2 k_4 k_6 k_8 k_{11} + \\
& k_1 k_2 k_4 k_5 k_7 k_8 k_{11} + k_1 k_3 k_4 k_5 k_7 k_8 k_{11} + k_1 k_2 k_4 k_6 k_7 k_8 k_{11} + k_1 k_3 k_4 k_6 k_7 k_8 k_{11} + \\
& k_1 k_2 k_3 k_4 k_5 k_9 k_{11} + k_1 k_3^2 k_4 k_5 k_9 k_{11} + k_1 k_2 k_3 k_4 k_6 k_9 k_{11} + k_1 k_3^2 k_4 k_6 k_9 k_{11} + \\
& k_1 k_2 k_4 k_5 k_7 k_9 k_{11} + k_1 k_3 k_4 k_5 k_7 k_9 k_{11} + k_1 k_2 k_4 k_6 k_7 k_9 k_{11} + k_1 k_3 k_4 k_6 k_7 k_9 k_{11} + \\
& k_1 k_3 k_4 k_5 k_8 k_{10} k_{11} + k_1 k_2 k_4 k_6 k_8 k_{10} k_{11} + 2 k_1 k_3 k_4 k_6 k_8 k_{10} k_{11} + k_1 k_2 k_4 k_7 \\
& k_8 k_{10} k_{11} + k_1 k_3 k_4 k_7 k_8 k_{10} k_{11} + k_1 k_4 k_5 k_7 k_8 k_{10} k_{11} + k_1 k_4 k_6 k_7 k_8 k_{10} k_{11} + \\
& k_1 k_3 k_4 k_5 k_9 k_{10} k_{11} + k_1 k_2 k_4 k_6 k_9 k_{10} k_{11} + 2 k_1 k_3 k_4 k_6 k_9 k_{10} k_{11} + k_1 k_2 k_4 k_7 \\
& k_9 k_{10} k_{11} + k_1 k_3 k_4 k_7 k_9 k_{10} k_{11} + k_1 k_4 k_5 k_7 k_9 k_{10} k_{11} + k_1 k_4 k_6 k_7 k_9 k_{10} k_{11} + \\
& k_1 k_2 k_3 k_4 k_8 k_{11}^2 + k_1 k_3^2 k_4 k_8 k_{11}^2 + k_1 k_2 k_4 k_7 k_8 k_{11}^2 + k_1 k_3 k_4 k_7 k_8 k_{11}^2 + \\
& k_1 k_2 k_3 k_4 k_9 k_{11}^2 + k_1 k_3^2 k_4 k_9 k_{11}^2 + k_1 k_2 k_4 k_7 k_9 k_{11}^2 + k_1 k_3 k_4 k_7 k_9 k_{11}^2 \left. \right) x_3)
\end{aligned}$$

$$\begin{aligned}
\mathbf{factor} = & k_1^2 k_3 k_4 k_5 k_9 k_{10} + k_1^2 k_3 k_4 k_6 k_9 k_{10} - k_1^2 k_4 k_5 k_6 k_9 k_{10} - \\
& k_1^2 k_4 k_6^2 k_9 k_{10} - k_1^2 k_4 k_5 k_6 k_{10}^2 - k_1^2 k_4 k_6^2 k_{10}^2 - k_1^2 k_4 k_5 k_7 k_{10}^2 - k_1^2 k_4 k_6 k_7 k_{10}^2 - \\
& k_1 k_2 k_3 k_4^2 k_8 k_{11} - k_1 k_3^2 k_4^2 k_8 k_{11} + k_1 k_2 k_4^2 k_6 k_8 k_{11} + k_1 k_3 k_4^2 k_6 k_8 k_{11} - \\
& k_1^2 k_3 k_4 k_5 k_{10} k_{11} - k_1^2 k_3 k_4 k_6 k_{10} k_{11} - k_1 k_2 k_4^2 k_6 k_{10} k_{11} - k_1 k_3 k_4^2 k_6 k_{10} k_{11} - \\
& k_1 k_2 k_4^2 k_7 k_{10} k_{11} - k_1 k_3 k_4^2 k_7 k_{10} k_{11} - k_1^2 k_4 k_5 k_7 k_{10} k_{11} - k_1^2 k_4 k_6 k_7 k_{10} k_{11} - \\
& k_1 k_2 k_3 k_4^2 k_{11}^2 - k_1 k_3^2 k_4^2 k_{11}^2 - k_1 k_2 k_4^2 k_7 k_{11}^2 - k_1 k_3 k_4^2 k_7 k_{11}^2;
\end{aligned}$$

**Factor[*factor*]**

$$\begin{aligned}
& k_1 k_4 \left( k_1 k_3 k_5 k_9 k_{10} + k_1 k_3 k_6 k_9 k_{10} - k_1 k_5 k_6 k_9 k_{10} - k_1 k_6^2 k_9 k_{10} - \right. \\
& k_1 k_5 k_6 k_{10}^2 - k_1 k_6^2 k_{10}^2 - k_1 k_5 k_7 k_{10}^2 - k_1 k_6 k_7 k_{10}^2 - k_2 k_3 k_4 k_8 k_{11} - k_3^2 k_4 k_8 k_{11} + \\
& k_2 k_4 k_6 k_8 k_{11} + k_3 k_4 k_6 k_8 k_{11} - k_1 k_3 k_5 k_{10} k_{11} - k_1 k_3 k_6 k_{10} k_{11} - k_2 k_4 k_6 k_{10} k_{11} - \\
& k_3 k_4 k_6 k_{10} k_{11} - k_2 k_4 k_7 k_{10} k_{11} - k_3 k_4 k_7 k_{10} k_{11} - k_1 k_5 k_7 k_{10} k_{11} - \\
& k_1 k_6 k_7 k_{10} k_{11} - k_2 k_3 k_4 k_{11}^2 - k_3^2 k_4 k_{11}^2 - k_2 k_4 k_7 k_{11}^2 - k_3 k_4 k_7 k_{11}^2 \left. \right)
\end{aligned}$$

$$\begin{aligned}
\mathbf{term} = & k_1 k_3 k_5 k_9 k_{10} + k_1 k_3 k_6 k_9 k_{10} - k_1 k_5 k_6 k_9 k_{10} - k_1 k_6^2 k_9 k_{10} - \\
& k_1 k_5 k_6 k_{10}^2 - k_1 k_6^2 k_{10}^2 - k_1 k_5 k_7 k_{10}^2 - k_1 k_6 k_7 k_{10}^2 - k_2 k_3 k_4 k_8 k_{11} - k_3^2 k_4 k_8 k_{11} + \\
& k_2 k_4 k_6 k_8 k_{11} + k_3 k_4 k_6 k_8 k_{11} - k_1 k_3 k_5 k_{10} k_{11} - k_1 k_3 k_6 k_{10} k_{11} - k_2 k_4 k_6 k_{10} k_{11} - \\
& k_3 k_4 k_6 k_{10} k_{11} - k_2 k_4 k_7 k_{10} k_{11} - k_3 k_4 k_7 k_{10} k_{11} - k_1 k_5 k_7 k_{10} k_{11} - \\
& k_1 k_6 k_7 k_{10} k_{11} - k_2 k_3 k_4 k_{11}^2 - k_3^2 k_4 k_{11}^2 - k_2 k_4 k_7 k_{11}^2 - k_3 k_4 k_7 k_{11}^2;
\end{aligned}$$

**simplTerm = FullSimplify[*term*]**

$$\begin{aligned}
& - (k_2 + k_3) k_4 k_{11} (k_6 (-k_8 + k_{10}) + k_3 (k_8 + k_{11}) + k_7 (k_{10} + k_{11})) - \\
& k_1 (k_5 + k_6) k_{10} (k_6 (k_9 + k_{10}) + k_3 (-k_9 + k_{11}) + k_7 (k_{10} + k_{11}))
\end{aligned}$$

$$\begin{aligned} \text{simplerTerm} = & \text{Distribute}[\text{simplTerm} / (k_1 * k_4)] /. \{(k_2 + k_3) / k_1 \rightarrow M_1, (k_5 + k_6) / k_4 \rightarrow M_2\} \\ & - k_{11} (k_6 (-k_8 + k_{10}) + k_3 (k_8 + k_{11}) + k_7 (k_{10} + k_{11})) M_1 - \\ & k_{10} (k_6 (k_9 + k_{10}) + k_3 (-k_9 + k_{11}) + k_7 (k_{10} + k_{11})) M_2 \end{aligned}$$

This above term larger than 0 should be the necessary condition.

$$\text{condition} = \text{simplerTerm} > 0$$

$$\begin{aligned} & - k_{11} (k_6 (-k_8 + k_{10}) + k_3 (k_8 + k_{11}) + k_7 (k_{10} + k_{11})) M_1 - \\ & k_{10} (k_6 (k_9 + k_{10}) + k_3 (-k_9 + k_{11}) + k_7 (k_{10} + k_{11})) M_2 > 0 \end{aligned}$$

$$\text{Simplify}[\text{condition}]$$

$$\begin{aligned} & k_{11} (k_6 (-k_8 + k_{10}) + k_3 (k_8 + k_{11}) + k_7 (k_{10} + k_{11})) M_1 + \\ & k_{10} (k_6 (k_9 + k_{10}) + k_3 (-k_9 + k_{11}) + k_7 (k_{10} + k_{11})) M_2 < 0 \end{aligned}$$

By manual simplifying the term, we can have:

$$\begin{aligned} \text{simpleCond} = & (k_3 - k_6) * (M_2 * k_9 * k_{10} - M_1 * k_8 * k_{11}) > \\ & (k_{11} * M_1 + k_{10} * M_2) * ((k_6 * k_{10} + k_3 * k_{11}) + k_7 * (k_{10} + k_{11})) \\ & (k_3 - k_6) (-k_8 k_{11} M_1 + k_9 k_{10} M_2) > (k_6 k_{10} + k_3 k_{11} + k_7 (k_{10} + k_{11})) (k_{11} M_1 + k_{10} M_2) \end{aligned}$$

$$\begin{aligned} \text{left} = & (k_3 - k_6) * (M_2 * k_9 * k_{10} - M_1 * k_8 * k_{11}) /. \{M_1 \rightarrow (k_2 + k_3) / k_1, M_2 \rightarrow (k_5 + k_6) / k_4\} \\ & (k_3 - k_6) \left( \frac{(k_5 + k_6) k_9 k_{10}}{k_4} - \frac{(k_2 + k_3) k_8 k_{11}}{k_1} \right) \end{aligned}$$

$$\begin{aligned} \text{right} = & (k_{11} * M_1 + k_{10} * M_2) * ((k_6 * k_{10} + k_3 * k_{11}) + k_7 * (k_{10} + k_{11})) /. \\ & \{M_1 \rightarrow (k_2 + k_3) / k_1, M_2 \rightarrow (k_5 + k_6) / k_4\} \\ & \left( \frac{(k_5 + k_6) k_{10}}{k_4} + \frac{(k_2 + k_3) k_{11}}{k_1} \right) (k_6 k_{10} + k_3 k_{11} + k_7 (k_{10} + k_{11})) \end{aligned}$$

To fullfil the assumption of thermodynamic conditions for the reversible reactions, we have the the constraint:

$$\frac{k_1 k_{10}}{k_2 k_{11}} = \frac{k_4 k_8}{k_5 k_9}.$$

This will give us a even simple condition. Then we will example how will this condition result in the parameter space for multistationarity.

$$\text{oriCond} = \text{simpleCond} /. \{M_1 \rightarrow (k_2 + k_3) / k_1, M_2 \rightarrow (k_5 + k_6) / k_4\}$$

$$\begin{aligned} & (k_3 - k_6) \left( \frac{(k_5 + k_6) k_9 k_{10}}{k_4} - \frac{(k_2 + k_3) k_8 k_{11}}{k_1} \right) > \\ & \left( \frac{(k_5 + k_6) k_{10}}{k_4} + \frac{(k_2 + k_3) k_{11}}{k_1} \right) (k_6 k_{10} + k_3 k_{11} + k_7 (k_{10} + k_{11})) \end{aligned}$$

$$\text{Simplify}[\text{oriCond}, \text{Assumptions} \rightarrow \frac{k_1 k_{10}}{k_2 k_{11}} == \frac{k_4 k_8}{k_5 k_9}]$$

$$\begin{aligned} & \frac{(k_3 - k_6) (k_1 k_6 k_9 k_{10} - k_3 k_4 k_8 k_{11})}{k_1 k_4} > \\ & \left( \frac{(k_5 + k_6) k_{10}}{k_4} + \frac{(k_2 + k_3) k_{11}}{k_1} \right) ((k_6 + k_7) k_{10} + (k_3 + k_7) k_{11}) \end{aligned}$$

Better to do it manually, then we have the condition with thermodynamic constraint:

**thermoCond =**

$$(k_3 - k_6) (k_6 k_2 - k_3 k_5) > \left( \frac{k_2}{k_9} \times \frac{k_5^2 + k_6}{k_5} + \frac{k_5}{k_8} \times \frac{k_2^2 + k_3}{k_2} \right) ((k_6 + k_7) k_{10} + (k_3 + k_7) k_{11})$$

$$(k_3 - k_6) (-k_3 k_5 + k_2 k_6) > \left( \frac{(k_2^2 + k_3) k_5}{k_2 k_8} + \frac{k_2 (k_5^2 + k_6)}{k_5 k_9} \right) ((k_6 + k_7) k_{10} + (k_3 + k_7) k_{11})$$

From the above condition, we can get some general idea that in order to satisfy the thermodynamic condition we should have:

Necessarily:

$$k_3 > k_6 \text{ and } k_2 > k_5$$

or

$$k_3 < k_6 \text{ and } k_5 > k_2$$

With additional (sufficiently):

$$k_8, k_9 \gg k_{10}, k_{11} \text{ and } k_7, k_{10}, k_{11} \approx 0$$

## Sampling the parameters

Here we try to sampling the parameters by enforcing the thermodynamic constraint. The parameters are sampled in biologically meaningful ranges.

```
In[321]:= ClearAll["Global`*"];
A = Table[0, {11}, {6}];
A[[1]][[1]] = -1;
A[[1]][[3]] = -1;
A[[1]][[5]] = 1;
A[[2]] = -A[[1]];
A[[3]][[3]] = 1; A[[3]][[2]] = 1; A[[3]][[5]] = -1;
A[[4]][[1]] = -1;
A[[4]][[4]] = -1;
A[[4]][[6]] = 1;
A[[5]] = -A[[4]];
A[[6]][[4]] = 1;
A[[6]][[2]] = 1;
A[[6]][[6]] = -1;
A[[7]][[2]] = -1;
A[[7]][[1]] = 1;
A[[8]][[3]] = -1; A[[8]][[4]] = 1; A[[9]] = -A[[8]];
A[[10]][[5]] = -1; A[[10]][[6]] = 1; A[[11]] = -A[[10]];
stoiM = Transpose[A];
(* Now we construct the rate vector *)
ks = {k1 x x3 x x1, k2 x x5, k3 x x5, k4 x x4 x x1,
      k5 x x6, k6 x x6, k7 x x2, k8 x x3, k9 x x4, k10 x x5, k11 x x6};
ssEqns = stoiM.ks;
mC = RowReduce[NullSpace[A]];
subEqns = {ssEqns[[2]], ssEqns[[4]],
           ssEqns[[5]], ssEqns[[6]], x1 + x2 + x5 + x6 - T1, x3 + x4 + x5 + x6 - T2};
jacobian = D[subEqns, {{x1, x2, x3, x4, x5, x6}}];
detJ = Collect[Distribute[Det[jacobian]], {x1, x2, x3, x4, x5, x6}];
solution =
  Solve[{subEqns[[1]], subEqns[[2]], subEqns[[3]], subEqns[[4]] == 0},
        {x2, x4, x5, x6}];
detSubs = Replace[detJ, solution[[1]], {0, Infinity}];
(* Equivalent to detSubs=detJ/.solution[[1]]; *)
polSubs = Numerator[Together[detSubs]];
finalSubs = Collect[Distribute[polSubs], x_, FactorTerms];
(*The above code is the same as first section*)
```

```

bistableKs = {};
bistableParSets = {};
SeedRandom[];
Timing[
  Do[{
    k1 = 10^(RandomReal[] * 6 - 3);
    k2 = 10^(RandomReal[] * 6 - 3);
    k3 = 10^(RandomReal[] * 6 - 3);
    k4 = 10^(RandomReal[] * 6 - 3);
    k5 = 10^(RandomReal[] * 6 - 3);
    k6 = 10^(RandomReal[] * 6 - 3);
    k7 = 10^(RandomReal[] * 6 - 3);
    k8 = 10^(RandomReal[] * 6 - 3);
    k9 = 10^(RandomReal[] * 6 - 3);
    k10 = 10^(RandomReal[] * 6 - 3);
    k11 = 10^(RandomReal[] * 6 - 3);
    left = (k3 - k6)  $\left( \frac{(k5 + k6) k9 k10}{k4} - \frac{(k2 + k3) k8 k11}{k1} \right)$ ;
    right =  $\left( \frac{(k5 + k6) k10}{k4} + \frac{(k2 + k3) k11}{k1} \right) (k6 k10 + k3 k11 + k7 (k10 + k11))$ ;
    If[left > right, {
      AppendTo[bistableKs,
        {k1, k2, k3, k4, k5, k6, k7, k8, k9, k10, k11, left, right}];
      counter = 1; hitQ = 0;
      While[hitQ == 0 && counter ≤ 10, {
        x1 = 10^(RandomReal[] * 4 - 3);
        finalSol =
          NSolve[finalSubs == 0 /. {k1 → k1, k2 → k2, k3 → k3, k4 → k4, k5 → k5, k6 → k6,
            k7 → k7, k8 → k8, k9 → k9, k10 → k10, k11 → k11, x1 → x1}, {x3}];
        x3 = x3 /. finalSol[[1]];
        realSol = solution /. {k1 → k1, k2 → k2, k3 → k3, k4 → k4, k5 → k5, k6 → k6,
          k7 → k7, k8 → k8, k9 → k9, k10 → k10, k11 → k11, x1 → x1, x3 → x3};
        T1 = (x1 + x2 + x5 + x6) /. Flatten[Append[{x1 → x1, x3 → x3}, realSol[[1]]]];
        T2 = (x3 + x4 + x5 + x6) /. Flatten[Append[{x1 → x1, x3 → x3}, realSol[[1]]]];
        If[10^(-3) ≤ T1 ≤ 10 && 10^(-3) ≤ T2 ≤ 10, {
          AppendTo[bistableParSets,
            {k1, k2, k3, k4, k5, k6, k7, k8, k9, k10, k11, T1, T2, left, right}];
          hitQ = 1;
        }];
        counter++;
      }];
    }, {i, 100000}];
]

```

Out[342]= {894.495, Null}

In[343]= Length[bistableParSets]

Out[343]= 185

In[344]= InputForm[bistableParSets]

Out[344]/InputForm=

```

{{214.29521185891113, 0.001210493083523859, 0.0062549573931550695, 378.601828511001, 0.
0.4276693186924565, 20.970372496790855, 0.8250839238764675, 0.0021783636770672855, 0.
4.891231884501928, 1.0371730438522756*^-6, 8.587361296527493*^-9}, {325.8726416161673
6.774854182923554, 233.03346062904188, 13.325429232884126, 0.2254348261481237, 0.0011
0.2919548480498236, 1.4137994220223729, 0.0038057433168796834, 0.8938918568974258, 0.
0.028478190071270573}, {949.6081440480004, 19.341945464299453, 428.49788701333125, 76

```

0.007737121221412035, 0.42730430284399046, 26.998265272025137, 17.39390435708959, 538  
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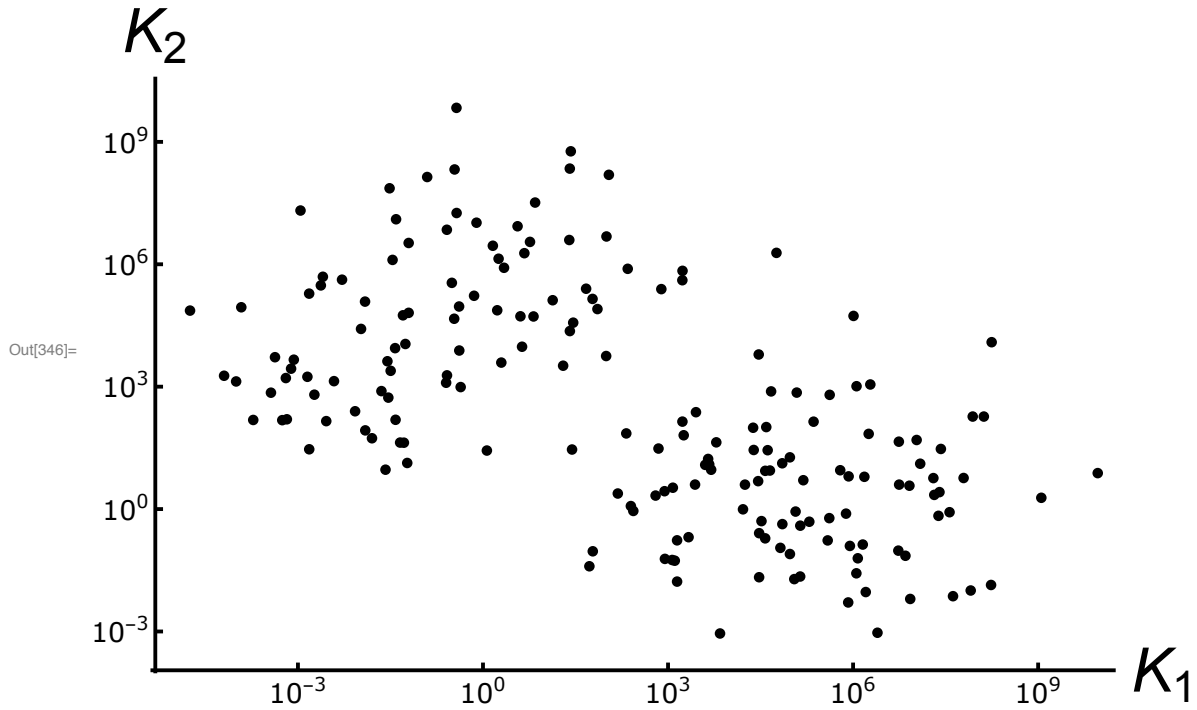
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```
In[345]:= transposedBiKs = Transpose[bistableParSets];
biParK1 =  $\frac{\text{transposedBiKs}[[1]] * \text{transposedBiKs}[[10]]}{\text{transposedBiKs}[[2]] * \text{transposedBiKs}[[11]]}$ ;
biParK2 =  $\frac{\text{transposedBiKs}[[4]] * \text{transposedBiKs}[[8]]}{\text{transposedBiKs}[[5]] * \text{transposedBiKs}[[9]]}$ ;
```

```

In[346]:= biPlot = ListLogLogPlot[Transpose[{biParK1, biParK2}],
  ImageSize → Large, PlotRange → Full, PlotLabel → None,
  LabelStyle → {32, GrayLevel[0]}, AxesLabel → {"K1", "K2"},
  Ticks → {Table[{10^(3 k), Superscript[10, 3 k]}, {k, -2, 3}],
    Table[{10^(3 k), Superscript[10, 3 k]}, {k, -2, 3}]}, TicksStyle →
    Directive["Label", 14], AxesStyle → Thick, PlotTheme → "Monochrome"]

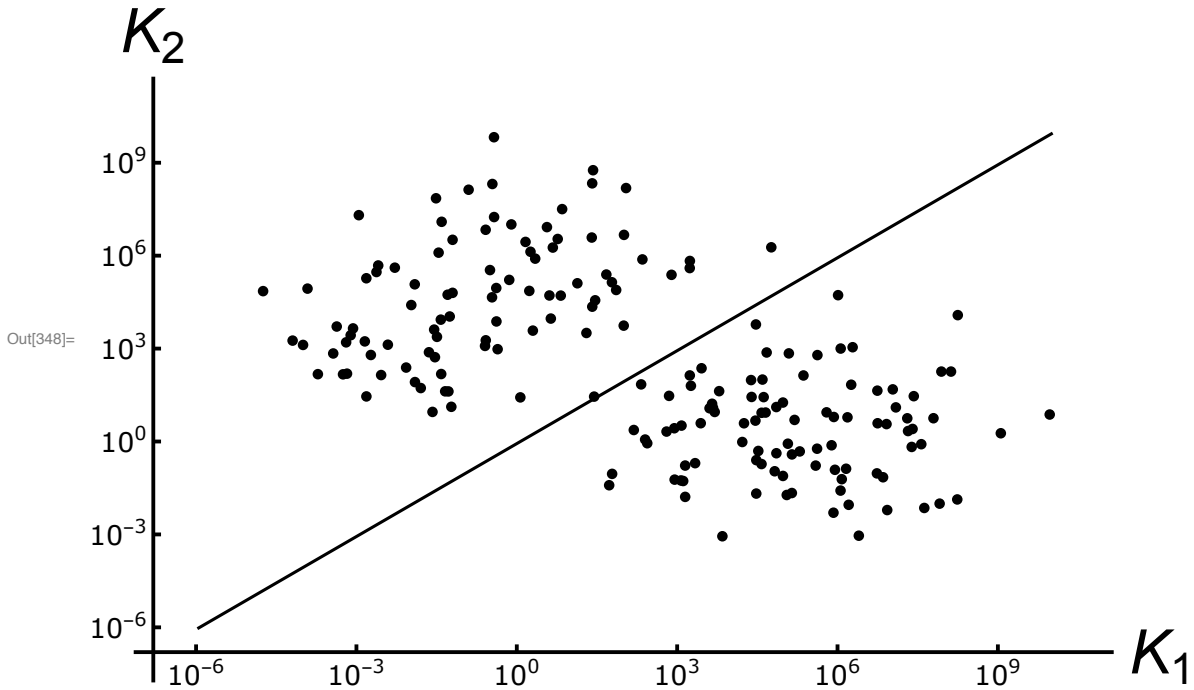
```



```

In[348]:= Show[LogLogPlot[x, {x, 10^(-6), 10^10}, PlotRange -> Full,
  ImageSize -> Large, PlotTheme -> "Monochrome", PlotLabel -> None,
  LabelStyle -> {32, GrayLevel[0]}, AxesLabel -> {"K1", "K2"},
  Ticks -> {Table[{10^(3 k), Superscript[10, 3 k]}, {k, -2, 3}],
    Table[{10^(3 k), Superscript[10, 3 k]}, {k, -2, 3}]},
  TicksStyle -> Directive["Label", 14], AxesStyle -> Thick], biPlot]

```



```

In[349]:= Length[bistableKs]

```

Out[349]= 14 502

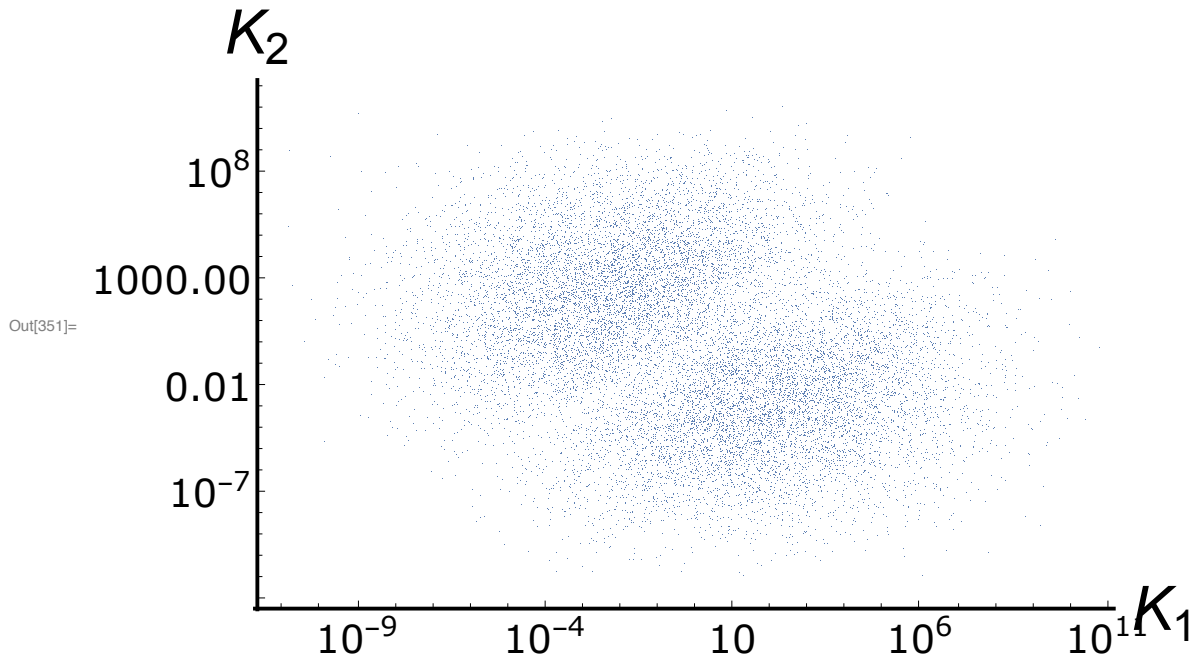
```

In[350]:= transposedKs = Transpose[bistableKs];
parK1 =  $\frac{\text{transposedKs}[[1]] * \text{transposedKs}[[10]]}{\text{transposedKs}[[2]] * \text{transposedKs}[[11]]}$ ;
parK2 =  $\frac{\text{transposedKs}[[4]] * \text{transposedKs}[[8]]}{\text{transposedKs}[[5]] * \text{transposedKs}[[9]]}$ ;

```



```
In[351]:= plot = ListLogLogPlot[Transpose[{parK1, parK2}], AxesLabel → {"K1", "K2"},
  ImageSize → Large, PlotRange → Full, LabelStyle → {32, GrayLevel[0]},
  AxesStyle → Thick, Ticks → Automatic, TicksStyle → Directive["Label", 20]]
```



```
In[353]:= Show[LogLogPlot[x, {x, 10^(-11), 10^11}, PlotRange → Full, ImageSize → Large,
  PlotLabel → None, LabelStyle → {32, GrayLevel[0]}, AxesLabel → {"K1", "K2"},
  Ticks → Automatic(*{Table[{10^(3 k), Superscript[10, 3k]}, {k, -2, 3}],
  Table[{10^(3 k), Superscript[10, 3k]}, {k, -2, 3}]}*),
  TicksStyle → Directive["Label", 14], AxesStyle → Thick,
  PlotTheme → "Monochrome"], plot]
```

