Supporting Information I

5-*exo*-Selective Asymmetric Bromolactonization of Stilbenecarboxylic Acids Catalyzed by Phenol-bearing Chiral Thiourea

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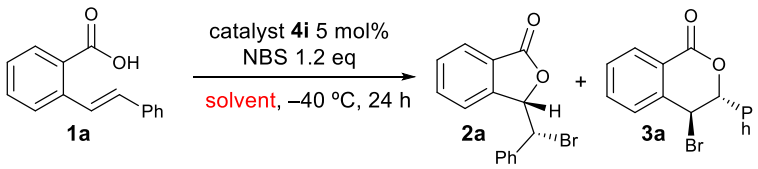
1. General procedure

All non-aqueous reactions were carried out under a positive atmosphere of argon in dried glassware. Reactions were monitored by thin-layer chromatography (TLC) using Merck TLC silica gel 60 F_{254}. Column chromatography was performed using Silica Gel 60N (particle size 0.040–0.050 mm) purchased from Kanto Chemical Co., Inc. Nuclear magnetic resonance (NMR) spectra were recorded on a Bruker AV-400N instrument. The chemical shifts (δ) are reported in parts per million relative to tetramethylsilane (0 ppm) for ^{1}H and $CDCl_3$ (77.0 ppm), DMSO-d_6 (39.5 ppm), or acetone-d_6 (206.7 and 30.4 ppm) for ^{13}C. The coupling constants (*J*) are presented in hertz. The following abbreviations were used to explain NMR peak multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. Mass spectra were recorded on a SHIMADZU LCMS-IT-TOF fitted with an ESI. IR spectroscopy was recorded using an attenuated total reflectance FTIR, and the wavenumbers of maximum absorption peaks are reported in cm^{-1}. Optical rotations were measured using a JASCO P-2200 polarimeter (concentration in g dL^{-1}). High performance liquid chromatography (HPLC) analyses were performed on a SHIMADZU analytical system equipped with two LC-20AT pumps. Melting point was determined on J-SCIENCE RFS-10.

2. Solvent Effect on the Reaction

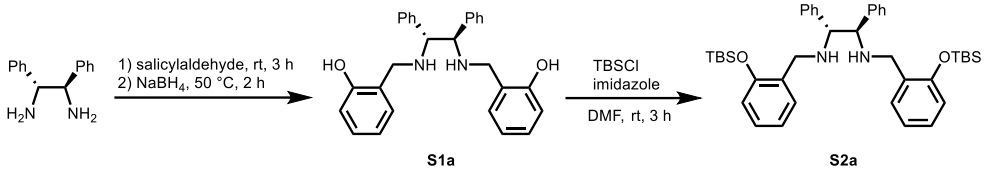
Table S1. Optimization of reaction solvents[a]



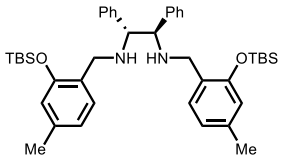
entry	solvent	yield[b]	2a:3a[c]	er of 2a[d]
1	CH_2Cl_2	79%	2:1	92:8
2	toluene	trace	-	-
3	CH_2Cl_2/toluene (1:1)	41%	3:2	76:24
4	PhCl	64%	5:1	71:29
5	$CHCl_3$	67%	1:8	83:17

[a] Reaction was conducted using **1a** (0.1 mmol), NBS (0.12 mmol), and **4i** (5 μmol) in solvent (2 mL). Remaining bromine species were quenched by aq $Na_2S_2O_3$ after 24 h. Hyphens in the table denote "not determined." [b] Combined yield of 2a and 3a. [c] Determined by ^{1}H NMR. [d] Determined by chiral HPLC analysis. The enantiomer ratio of **3**a was generally low (50:50–55:45).

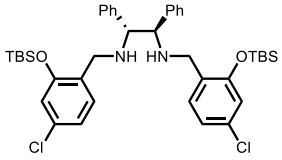
3. Catalyst Synthesis



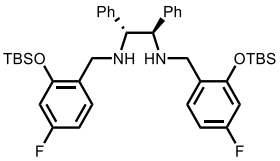
Typical Procedure for Synthesis of N-Alkylated Diamine. (1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)benzyl)-1,2-diphenylethane-1,2-diamine (S2a): Salicylaldehyde (610 mg, 5.00 mmol) and (*R*,*R*)-diphenyl-1,2-ethanediamine (530 mg, 2.50 mmol) were stirred in ethanol (15 mL) for 3 h at rt. To the mixture was added $NaBH_4$ (1.00 g, 25.8 mmol) in one portion at 0 °C, and then the solution was stirred at 50 °C for 2 h. The solvent was removed by evaporation, and to the residue was added H_2O (20 mL). The whole was extracted with EtOAc (20 mL × 3), and the combined organic layers were washed with brine, dried with Na_2SO_4, and concentrated under reduced pressure to give 2,2'-((3*R*,4*R*)-2,5-Diaza-3,4-diphenylhexamethylene)diphenol (**S1a**) (1.00 g) as a colorless oil, which was used in the next reaction without further purification. A mixture of diamine **S1a** (1.00 g, 2.36 mmol), imidazole (802 mg, 11.8 mmol) and TBSCl (885 mg, 5.90 mmol) in DMF (30 mL) was stirred for 3 h at rt. The mixture was poured into water (100 mL), and the whole was extracted with EtOAc (30 mL × 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 15:1) to give the title compound (1.46 g, 82 %) as colorless oil: $[\alpha]_D^{29}$ +19.9 (*c* 1.54, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.20 (d, *J* = 7.5, 2H), 7.10–7.05 (m, 8H), 7.02–7.00 (m, 4H), 6.87 (t, *J* = 7.5, 2H), 6.71 (d, *J* = 7.5, 2H), 3.63 (s, 2H), 3.58 (d, *J* = 12.0, 2H), 3.89 (d, *J* = 12.0, 2H), 0.79 (s, 18 H), 0.10 (s, 6H), 0.08 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 153.6 (C), 141.5 (C), 131.1 (C), 129.7 (CH), 128.1 (CH), 127.9 (CH), 127.4 (CH), 126.7 (CH), 121.0 (CH), 118.5 (CH), 68.5 (CH), 46.4 (CH_2), 25.8 (CH_3), 18.2 (C), −4.2 (CH_3). **MS** (ESI) *m*/*z*: 653 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{57}N_2O_2Si_2$, 653.3959; found, 653.3969. **IR** (NaCl): 3340, 3060, 2936, 1594, 1490, 1267, 1104, 917, 835, 786.



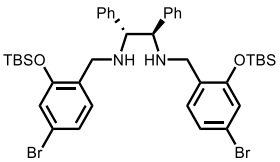
(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-methylbenzyl)-1,2-diphenylethane-1,2-diamine (S2f): The typical procedure using 2-hydroxy-4-methylbenzaldehyde (210 mg, 1.54 mmol), $NaBH_4$ (260 mg, 7.70 mmol), EtOH (5 mL), imidazole (270 mg, 3.97 mmol), TBSCl (360 mg, 2.40 mmol), and DMF (5 mL) gave the title compound (340 mg, 65%) as colorless oil: $[\alpha]_D^{31}$ –8.23 (*c* 1.36, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.09–7.07 (m, 10H), 7.00 (m, 4H), 6.64 (d, *J* = 8.0, 2H), 3.71 (s, 2H), 3.63 (d, *J* = 13.0, 2H), 3.43 (d, *J* = 13.0, 2H), 2.27 (s, 6H), 0.88 (s, 18H), 0.11 (s, 6H), 0.09 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 153.4 (C), 141.5 (C), 137.2 (C), 129.4 (CH), 127.4 (C), 128.2 (CH), 127.8 (CH), 127.0 (CH), 121.6 (CH), 119.3 (CH), 68.4 (CH), 46.0 (CH_2), 25.8 (CH_3), 21.2 (CH_3), 18.2 (C), –4.2 (CH_3). **MS** (ESI) *m*/*z*: 681 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{42}H_{61}N_2O_2Si_2$, 681.4272; found, 681.4274. **IR** (NaCl): 3270, 2950, 2920, 1620, 1450, 1300, 1120, 850, 850, 770.



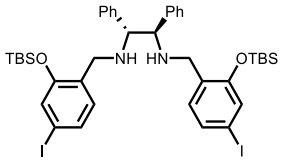
(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-chlorobenzyl)-1,2-diphenylethane-1,2-diamine (S2g): The typical procedure using 2-hydroxy-4-chlorobenzaldehyde (690 mg, 4.45 mmol), $NaBH_4$ (490 mg, 12.8 mmol), imidazole (480 mg, 7.06 mmol), TBSCl (550 mg, 3.67 mmol) and column chromatography (hexane/EtOAc 30:1) gave the title compound (750 mg, 70%) as colorless oil: $[\alpha]_D^{23}$ –25.0 (*c* 1.01, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.13–7.01 (m, 8H), 7.02–7.00 (m, 4H), 6.86 (dd, *J* = 8.0, 2.0, 2H), 6.71 (d, *J* = 2.0, 2H), 3.66 (s, 2H), 3.61 (d, *J* = 14.0, 2H), 3.42 (d, *J* = 14.0, 2H), 0.87 (s, 18H), 0.12 (s, 6H), 0.09 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 154.1 (C), 141.1 (C), 132.3 (C), 130.4 (CH), 129.7 (C), 127.9 (CH), 127.9 (CH), 126.8 (CH), 121.0 (CH), 118.8 (CH), 68.2 (CH), 45.9 (CH_2), 25.6 (CH_3), 18.1 (C), –4.2 (CH_3). **MS** (ESI) *m*/*z*: 721 (M + H), 723 (M + 2 + H), 725 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{55}N_2O_2Si_2Cl_2$, 721.3179; found, 721.3151. **IR** (NaCl): 3200, 2950, 2850, 1600, 1470, 1400, 1240, 940, 850, 780.



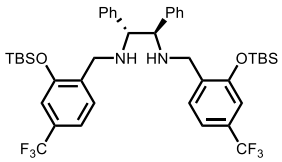
(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-fluorobenzyl)-1,2-diphenylethane-1,2-diamine (S2h): The typical procedure using 2-hydroxy-4-fluorobenzaldehyde (730 mg, 5.21 mmol), $NaBH_4$ (590 mg, 7.70 mmol), EtOH (10 mL), imidazole (570 mg, 8.38 mmol), TBSCl (550 mg, 3.67 mmol) and column chromatography (hexane/EtOAc 20:1) gave the title compound (820 mg, 73%) as colorless oil: $[\alpha]_D^{22}$ –20.3 (*c* 1.59, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.14–7.07 (m, 8H), 7.01–7.00 (m, 4H), 6.58 (td, *J* = 8.5, 2.5, 2H), 6.64 (dd, *J* = 10.5, 2.5, 2H), 3.66 (s, 2H), 3.59 (d, *J* = 14.0, 2H), 3.41 (d, *J* = 14.0, 2H), 0.87 (s, 18H), 0.12 (s, 6H), 0.09 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 162.0 (d, *J* = 243, C), 154.5 (d, *J* = 11, C), 141.3 (C), 130.4 (CH), 130.3 (CH), 128.0 (d, *J* = 7, CH), 126.9 (d, *J* = 4, C), 126.7 (CH), 107.4 (d, *J* = 21, CH), 105.9 (d, *J* = 21, CH), 68.3 (CH), 46.0 (CH_2), 25.7 (CH_3), 18.1 (C), –4.3 (CH_3). **MS** (ESI) *m*/*z*: 689 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{55}N_2O_2F_2Si_2$, 689.3770; found, 689.3783. **IR** (NaCl): 3300, 2950, 2880, 1620, 1470, 1460, 1270, 1150, 980, 850.



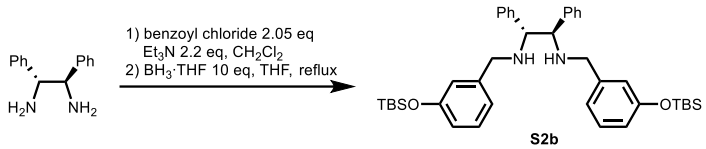
(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-bromobenzyl)-1,2-diphenylethane-1,2-diamine (S2i): The typical procedure using 2-hydroxy-4-bromobenzaldehyde (660 mg, 3.30 mmol), $NaBH_4$ (200 mg, 5.26 mmol), EtOH (20 mL), imidazole (530 mg, 7.70 mmol), TBSCl (700 mg, 4.62 mmol), DMF (10 mL), and column chromatography (hexane/EtOAc 20:1) gave the title compound (810 mg, 65%) as colorless oil: $[\alpha]_D^{23}$ –26.9 (*c* 1.04, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.12–7.09 (m, 6H), 7.01–6.99 (m, 8H), 6.85 (d, *J* = 2.0, 2H), 3.64 (s, 2H), 3.59 (d, *J* = 14.0, 2H), 3.39 (d, *J* = 14.0, 2H), 0.85 (s, 18H), 0.11 (s, 6H), 0.09 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 154.3 (C), 141.1 (C), 130.8 (CH), 130.2 (C), 130.0 (CH), 126.80 (CH), 126.78 (CH), 124.0 (CH), 121.7 (CH), 120.1 (C), 68.3 (CH), 45.8 (CH_2), 25.6 (CH_3), 18.1 (C), –4.2 (CH_3). **MS** (ESI) *m*/*z*: 809 (M + H), 811 (M + 2 + H), 813 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{55}N_2O_2Si_2Br_2$, 809.2169; found, 809.2200. **IR** (NaCl): 2940, 2850, 1600, 1460, 1390, 1260, 960, 850, 760, 690.



(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-iodobenzyl)-1,2-diphenylethane-1,2-diamine (S2j): The typical procedure using 2-hydroxy-4-iodobenzaldehyde (980 mg, 3.96 mmol), $NaBH_4$ (230 mg, 6.04 mmol), and EtOH (20 mL) gave **S1f** (940 mg, 70%) as colorless solid. The typical procedure using a part of **S1f** (500 mg, 0.739 mmol), TBSCl (332 mg, 2.20 mmol), imidazole (250 mg, 3.68 mmol), DMF (10 mL), and column chromatography (hexane/EtOAc 20:1) gave the title compound (590 mg, 88%) as colorless oil: $[\alpha]_D^{23}$ –18.4 (*c* 1.04, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.20 (dd, *J* = 8.0, 2.0, 2H), 7.13–7.09 (m, 6H), 7.04 (d, *J* = 2.0, 2H), 7.00 (m, 4H), 6.88 (d, *J* = 8.0, 2H), 3.64 (s, 2H), 3.58 (d, *J* = 14.0, 2H), 3.39 (d, *J* = 14.0, 2H), 0.86 (s, 18H), 0.10 (s, 6H), 0.08 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 154.3 (C), 141.1 (C), 131.1 (CH), 130.9 (C), 130.1 (CH), 127.9 (CH), 127.50 (CH), 127.47 (CH), 126.8 (CH), 91.4 (C), 68.2 (CH), 45.9 (CH_2), 25.6 (CH_3), 18.1 (C), –4.2 (CH_3). **MS** (ESI) *m*/*z*: 905 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{55}N_2O_2Si_2I_2$, 905.1892; found, 905.1857. **IR** (NaCl): 3200, 2950, 2880, 1560, 1490, 1380, 1220, 1125, 910, 810.

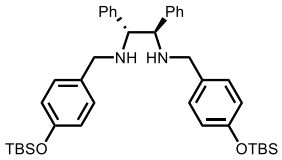


(1*R*,2*R*)-*N*,*N*′-Bis(2-(*tert*-butyldimethylsiloxy)-4-trifluoromethylbenzyl)-1,2-diphenylethane-1,2-diamine (S2k): The typical procedure using 2-hydroxy-4-trifluoromethylbenzaldehyde (1.25 g, 6.57 mmol), $NaBH_4$ (740 mg, 19.5 mmol), and EtOH (10 mL) gave **S1g** (1.30 g, 71%) as colorless solid. The typical procedure using a part of **S1g** (400 mg, 0.714 mmol), TBSCl (332 mg, 2.20 mmol), imidazole (242 mg, 3.56 mmol), DMF (10 mL), and column chromatography (hexane/EtOAc 20:1) gave the title compound (590 mg, 88%) as colorless oil: $[\alpha]_D^{23}$ –21.7 (*c* 1.16, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.25 (d, *J* = 8.0, 2H), 7.16–7.08 (m, 8H), 7.05–7.00 (m, 4H), 6.91 (s, 2H), 3.67 (s, 2H), 3.65 (d, *J* = 14.0, 2H), 3.51 (d, *J* = 14.0, 2H), 0.87 (s, 18H), 0.11 (s, 6H), 0.09 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 153.6 (C), 140.1 (C), 135.1 (C), 129.9 (CH), 129.8 (q, *J* = 32, C) 128.0 (CH), 127.9 (CH), 127.0 (CH), 124.0 (q, *J* = 270, C), 117.9 (CH), 115.1 (CH), 68.4 (CH), 46.1 (CH_2), 25.6 (CH_3), 18.1 (C), –4.3 (CH_3). **MS** (ESI) *m*/*z*: 789 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{42}H_{55}N_2O_2F_6Si_2$, 789.3706; found, 789.3688. **IR** (NaCl): 3340, 2960, 2860, 1630, 1600, 1530, 1420, 1330, 1240, 1180.

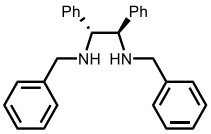


Typical Procedure for Acylation and Reduction of Diamine. (1*R*,2*R*)-*N*,*N*′-Bis(3-(*tert*-butyldimethylsiloxy)benzyl)-1, 2-diphenylethane-1,2-diamine (S2b): Under argon atmosphere, to a solution of (*R*,*R*)-diphenyl-1,2-ethanediamine (165 mg, 0.792 mmol) and Et_3N (0.30 mL, 2.1 mmol) in CH_2Cl_2 (8 mL) at 0 °C was added 3-(*tert*-butyldimethylsiloxy)benzoyl chloride (430 mg, 1.59 mmol). The solution was stirred for 1 h at rt. The reaction was quenched with 1 M HCl aq, and the whole mixture was extracted with CH_2Cl_2 (10 mL × 3). The combined organic layers were washed with 2 M HCl aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was dissolved in THF. Under argon atmosphere, to the solution was added a 1.0 M THF solution of BH_3·THF (1.8 mL, 1.8 mmol) at 0 °C. The mixture was

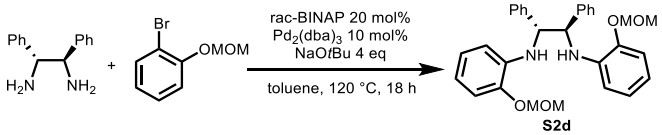
heated under reflux for 10 h. After cooling to 0 °C, MeOH was slowly added, and then the volatile materials were evaporated. The residue was purified by column chromatography (hexane/EtOAc 10:1) to give the title compound (120 mg, 20%) as yellow oil: $[\alpha]_D^{23}$ –14.3 (*c* 1.05, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.20–7.12 (m, 8H), 7.04–7.03 (m, 4H), 6.84 (d, *J* = 7.5, 2H), 6.74–6.70 (m, 4H), 3.71 (s, 2H), 3.63 (d, *J* = 13.0, 2H), 3.44 (d, *J* = 13.0, 2H), 2.36 (brs, 2H), 0.99 (s, 18H), 0.20 (s, 12H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 155.6 (C), 142.2 (C), 141.1 (C), 129.2 (CH), 128.0 (CH), 127.9 (CH), 126.9 (CH), 121.0 (CH), 119.8 (CH), 118.5 (CH), 68.1 (CH), 51.2 (CH_2), 27.7 (CH_3), 18.2 (C), –4.3 (CH_3). **MS** (ESI) *m*/*z*: 653 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{57}N_2O_2Si_2$, 653.3959; found, 653.3931. **IR** (NaCl): 3300, 2960, 2930, 1600, 1490, 1450, 1260, 1200, 850, 780.



(1*R*,2*R*)-*N*,*N*′-Bis(4-(*tert*-butyldimethylsiloxy)benzyl)-1,2-diphenylethane-1,2-diamine (S2c): The typical procedure using 4-(*tert*-butyldimethylsiloxy)benzoyl chloride (570 mg, 2.05 mmol), Et_3N (0.15 mL, 2.1 mmol), and a 1.0 M THF solution of BH_3·THF (10 mL, 10 mmol) gave the title compound (620 mg, 95 %) as colorless solid of mp 73.0–74.3 °C: $[\alpha]_D^{30}$ –19.8 (*c* 1.12, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.20–7.12 (m, 6H), 7.08–7.02 (m, 8H), 6.77–6.75 (m, 4H), 3.69 (s, 2H), 3.59 (d, *J* = 14.0, 2H), 3.41 (d, *J* = 14.0, 2H), 1.00 (s, 18H), 0.20 (s, 12H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 154.4 (C), 141.2 (C), 133.4 (C), 129.2 (CH), 128.0 (CH), 127.9 (CH), 126.8 (CH), 119.8 (CH), 68.3 (CH), 50.8 (CH_2), 25.7 (CH_3), 18.2 (C), −4.4 (CH_3). **MS** (ESI) *m*/*z*: 653 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{40}H_{57}N_2O_2Si_2$, 653.3959; found, 653.3965. **IR** (KBr): 3200, 2950, 2930, 2860, 1500, 1440, 1260, 920, 840, 780.



(1*R*,2*R*)-*N*,*N*′- Dibenzyl-1,2-diphenylethane-1,2-diamine (S1e): The typical procedure using benzoyl chloride (0.56 mL, 4.8 mmol), Et_3N (1.4 mL, 10 mmol), and a 1.0 M THF solution of BH_3·THF (35 mL, 35 mmol) gave the title compound (510 mg, 65 %) as colorless oil: $[\alpha]_D^{26}$ –25.5 (*c* 1.38, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.28 (m, 4H), 7.25–7.21 (m, 6H), 7.17–7.12 (m, 6H), 7.03 (m, 4H), 3.71 (s, 2H), 3.62 (d, *J* = 13.0, 2H), 3.49 (d, *J* = 13.0, 2H). ^{1}H NMR was in agreement with that reported.[1)]



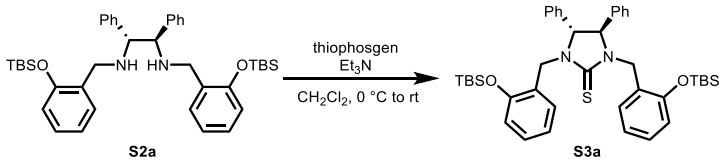
S2d

(1*R*,2*R*)-*N*,*N*-Bis(2-(methoxymethoxy)phenyl)-1,2-diphenylethane-1,2-diamine (S2d): Under argon atmosphere, to a mixture of $Pd_2(dba)_3$ (0.10 g, 0.10 mmol), *rac*-BINAP (0.12 g, 0.20 mmol), and NaO*t*Bu (380 mg, 3.95 mmol) was added (*R*,*R*)-diphenyl-1,2-ethanediamine (212 mg, 1.00 mmol) in toluene (5 mL). The mixture was stirred for 30 min at rt, and a solution of 1-bromo-2-(methoxymethoxy)benzene (0.56 g, 2.6 mmol) in toluene (2 mL) was added. The mixture was heated under reflux for 18 h. After cooling to rt, the mixture was filtered through celite, and then the filtrate was concentrated

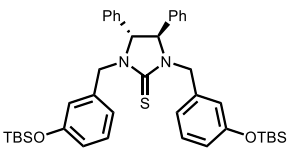
1) Kobayashi, S.; Matsubara, R.; Nakamura, Y.; Kitagawa, H.; Sugiura, M. *J. Am. Chem. Soc.* **2003**, *125*, 2507.

under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the title compound (500 mg, quant) as yellow solid of mp 108.8–110.3 °C: $[\alpha]_D^{26}$ +94.7 (*c* 1.16, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.22–7.18 (m, 10H), 6.94 (dd, *J* = 7.5, 1.5, 2H), 6.69 (t, *J* = 7.5, 1.5, 2H), 6.54 (t, *J* = 7.5, 1.5, 2H), 6.30 (dd, *J* = 7.5, 1.5, 2H), 5.23 (brs, 2H), 5.16 (d, *J* = 6.5, 2H), 5.11 (d, *J* = 6.5, 2H), 4.61 (s, 2H), 3.42 (6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 144.7 (C), 140.2 (C), 137.8 (C), 128.3 (CH), 127.4 (CH), 127.3(CH), 122.5 (CH), 117.1 (CH), 113.9 (CH), 112.1 (CH), 95.0 (CH_2), 63.9 (CH), 56.0 (CH_3). **MS** (ESI) *m/z:* 507 (M + H). **HRMS** (ESI) *m/z*: $[M + H]^+$ calcd for $C_{30}H_{32}N_2O_4Na$, 507.2260; found, 507.2284. **IR** (NaCl): 3400, 3065, 2950, 1600, 1500, 1453, 1253, 1150, 1077, 996.

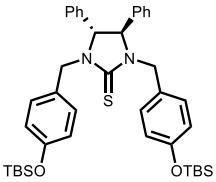
(4*R*,5*R*)-1,3-Bis(2-(methoxymethoxy)phenyl)-4,5-diphenyl imidazolinium tetrafluoroborate (S2d'): A mixture of **S2d** (97 mg, 0.20 mmol), NH_4BF_4 (31 mg, 0.30 mmol), and $CH(OEt)_3$ (2.0 mL, 12 mmol) was heated at 120 ºC for 3 h. After cooling to rt, the formed colorless precipitate was collected by filtration and washed with Et_2O to give the title compound as colorless solid (80 mg, 0.14 mmol) of mp 194.6–195.8 °C: $[\alpha]_D^{26}$ +284 (*c* 0.664, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 9.07 (s, 1H), 7.41–7.39 (m, 10H), 7.30–7.26 (m, 4H), 7.20 (dd, *J* = 8.0, 1.0, 2H), 6.96 (td, *J* = 8.0, 1.0, 2H), 5.77 (s, 2H), 5.33 (s, 4H), 3.51 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 158.3 (CH), 151.4 (C), 135.3 (C), 130.8 (CH), 130.1 (CH), 129.6 (CH), 127.4 (CH), 126.7 (CH), 123.2 (C), 122.6 (CH), 115.4 (CH), 95.7 (CH_2), 75.4 (CH), 56.6 (CH_3). **MS** (ESI) *m/z*: 495 (M – BF_4). **HRMS** (ESI) *m/z*: $[M - BF_4]^+$ calcd for $C_{31}H_{31}N_2O_4$, 495.2284; found, 495.2261. **IR** (KBr): 3080, 2915, 2360, 2341, 1620, 1588, 1497, 1269, 1156, 972.



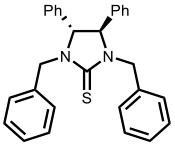
Typcal Procedure for Synthesis of Thiourea. (*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)benzyl)-4,5-diphenylimidazolidine-2-thione (S3a): To a solution of **S2a** (170 mg, 0.250 mmol) and Et_3N (0.12 mL 0.92 mmol) in CH_2Cl_2 (2.5 mL), was added thiophosgen (35 μL 0.46 mmol) at 0 °C. The mixture was stirred for 9 h at rt, and then water (10 mL) was added. The aqueous layer was separated and extracted with CH_2Cl_2 (10 mL × 2). The combined organic layers were washed brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 20:1) to give the title compound (100 mg, 55%) as colorless oil: $[\alpha]_D^{22}$ +135 (*c* 1.04, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.43 (d, *J* = 6.0, 2H), 7.28–7.26 (m, 6H), 7.10–7.04 (m, 6H), 6.93 (td, *J* = 7.5, 1.0, 2H), 6.68 (dd, *J* = 7.0, 1.0, 2H), 5.54 (d, *J* = 15.5, 2H), 4.41 (s, 2H), 4.30 (d, *J* = 15.5, 2H), 0.72 (s, 18H), 0.05 (s, 6H), −0.02 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.5 (C), 153.4 (C), 138.9 (C), 129.0 (CH), 128.8 (CH), 128.7 (CH), 128.5 (CH), 126.8 (CH), 125.5 (C), 121.3 (CH), 110.7 (CH), 69.3 (CH), 42.8 (CH_2), 25.5 (CH_3), 18.0 (C), –4.5 (CH_3). **MS** (ESI) *m/z*: 717 (M + Na). **HRMS** (ESI) *m/z*: $[M + H]^+$ calcd for $C_{41}H_{55}N_2O_2S$, 695.3523; found, 695.3504. **IR** (NaCl): 2972, 2856, 1948, 1730, 1599, 1582, 1258, 1105, 920, 778.



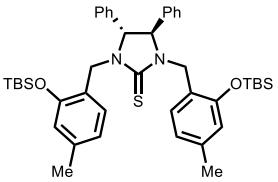
(*4R,5R*)-1,3-Bis(3-(*tert*-butyldimethylsiloxy)-4,5-diphenylimidazolidine-2-thione (S3b): The typical procedure using **S2b** (100 mg, 0.153 mmol), Et_3N (64 μL, 0.49 mmol), and thiophosgen (20 μL, 0.26 mmol) gave the title compound (70 mg, 67%) as yellow oil: $[\alpha]_D^{23}$ +87.5 (*c* 1.05, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.30–7.26 (m, 6H), 7.12 (t, *J* = 8.5, 2H), 6.98–6.96 (m, 4H), 6.84 (d, *J* = 7.5, 2H), 6.72–6.70 (m, 4H), 5.81 (d, *J* = 15.0, 2H), 4.3 (s, 2H), 3.70 (d, *J* = 15.0, 2H), 0.96 (s, 18H), 0.17 (s, 6H), 0.16 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.6 (C), 153.4 (C), 138.9 (C), 138.0 (C), 129.0 (CH), 128.7 (CH), 128.5 (CH), 128.0 (CH), 126.9 (CH), 121.3 (CH), 118.8 (CH), 69.2 (CH), 42.8 (CH_2), 20.6 (CH_3), 17.9 (C), –4.4 (CH_3). **MS** (ESI) *m*/*z*: 695 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{55}N_2O_2Si_2S$, 695.3523; found, 695.3535. **IR** (NaCl): 3020, 2953, 2860, 1615, 1450, 1410, 1270, 1210, 980, 860.



(*4R,5R*)-1,3-Bis(4-(*tert*-butyldimethylsiloxy)benzyl)-4,5-diphenylimidazolidine-2-thione (S3c): The typical procedure using **S2c** (110 mg, 0.168 mmol), Et_3N (64 μL, 0.49 mmol), and thiophosgen (21 μL, 0.27 mmol) gave the title compound (85.2 mg, 80%) as colorless solid of mp 115.2–116.7 °C: $[\alpha]_D^{31}$ +43.3 (*c* 1.09, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.29–7.25 (m, 6H), 7.11 (d, *J* = 8.0, 4H), 6.93 (m, 4H), 6.74 (d, *J* = 8.0, 4H), 5.79 (d, *J* = 15.0, 2H), 4.29 (s, 2H), 3.69 (d, *J* = 15.0, 2H), 0.96 (s, 18H), 0,17 (s, 12H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 182.2 (C), 155.2 (C), 138.4 (C), 129.8 (CH), 129.0 (CH), 128.8 (C), 128.6 (CH), 127.1 (CH), 120.1 (CH), 68.9 (CH), 48.3 (CH_2), 25.7 (CH_3), 18.2 (C), –4.4 (CH_3). **MS** (ESI) *m*/*z*: 695 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{55}N_2O_2Si_2S$, 695.3523; found, 695.3502. **IR** (NaCl): 2980, 2850, 1510, 1460, 1410, 1260, 1220, 1120, 910, 840.



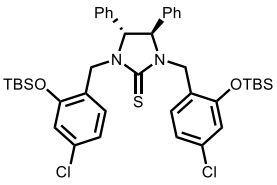
(*4R,5R*)-1,3-Dibenzyl-4,5-diphenylimidazolidine-2-thione (4e): The typical procedure using **S1e** (0.10 g, 0.25 mmol), Et_3N (0.10 mL, 0.75 mmol), thiophosgen (25 μL, 0.30 mmol) and column chromatography (hexane/EtOAc 10:1) gave the title compound (120 mg, quantity) as colorless solid of mp 171.1–172.2 °C: $[\alpha]_D^{31}$ +152 (*c* 0.153, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.30–7.23 (m, 16H), 6.97 (m, 4H), 5.87 (d, *J* = 15.0, 2H), 4.30 (s, 2H), 3.78 (d, *J* = 15.0, 2H). ^{1}H NMR was in agreement with that reported.[2)]



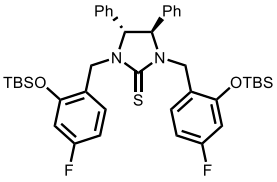
(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-methylbenzyl)-4,5-diphenylimidazolidine-2-thione (S3f): The typical procedure using **S2f** (170 mg, 0.250 mmol) and CH_2Cl_2 (10 mL) gave the title compound (100 mg, 55 %) as yellow oil: $[\alpha]_D^{23}$ +91.7 (*c* 1.54, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.31–7.26 (m, 8H), 7.04 (m, 4H), 7.75 (d, *J* = 8.0, 2H), 6.50 (s, 2H), 5.52 (d, *J* = 15.0, 2H), 4.40 (s, 2H), 4.23 (d, *J* = 15.0, 2H), 2.25 (s, 6H), 0.71 (s, 18H), 0.04 (s, 6H), 0.01 (s, 6H). **^{13}C**

2) Ryoda, A.; Yajima, N.; Haga, T.; Kumamoto, T.; Nakanishi, W.; Kawahata, M.; Yamaguchi, K.; Ishikawa, T. *J. Org. Chem.* 2008, 73, 1, 133.

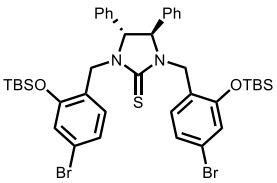
NMR ($CDCl_3$, 100 MHz): 183.4 (C), 153.2 (C), 139.0 (C), 137.9 (C), 129.0 (CH), 128.5 (CH), 128.4 (CH), 126.9 (CH), 123.3 (C), 122.1 (CH), 119.5 (CH), 69.0 (CH), 42.6 (CH_2), 25.5 (CH_3), 21.2 (CH_3). 17.9 (C), –4.4 (CH_3). **MS** (ESI) *m*/*z*: 723 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{43}H_{59}N_2O_2Si_2S$, 723.3836; found, 723.3863. **IR** (NaCl): 2950, 2910, 2860, 1470, 1400, 1320, 1280, 1120, 820, 770.



(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-chlorobenzyl)-4,5-diphenylimidazolidine-2-thione (S3g): The typical procedure using **S2g** (550 mg, 1.11 mmol), Et_3N (0.47 mL, 3.3 mmol), thiophosgen (93 μL, 1.2 mmol), CH_2Cl_2 (10 mL), and column chromatography (hexane/EtOAc 10:1) gave the title compound (800 mg, 94%) as colorless solid of mp 176.4–178.0 °C: $[\alpha]_D^{31}$ +76.0 (*c* 1.12, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.34 (d, *J* = 8.0, 2H), 7.30–7.24 (m, 6H), 7.01 (m, 4H), 6.91 (dd, *J* = 8.0, 2.0, 2H), 6.67 (d, *J* = 2.0, 2H), 5.48 (d, *J* = 16.0, 2H), 4.36 (s, 2H), 4.24 (d, *J* = 16.0, 2H), 0.71 (s, 18H), 0.06 (s, 6H), 0.00 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.6 (C), 154.0 (C), 138.5 (C), 133.0 (C), 129.5 (CH), 129.2 (CH), 128.7 (CH), 126.7 (CH), 125.2 (C), 121.5 (CH), 119.1 (CH), 69.3 (CH), 42.5 (CH_2), 25.4 (CH_3), 17.9 (C), –4.5 (CH_3). **MS** (ESI) *m*/*z:* 763 (M + H), 765 (M + 2 + H), 767 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{53}N_2O_2Si_2SCl_2$, 763.2743; found, 763.2723. **IR** (KBr): 2950, 2850, 1590, 1560, 1480, 1400, 1350, 1270, 1200, 950.

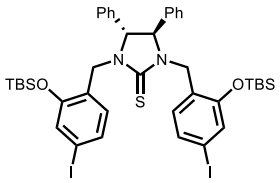


(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-fluorobenzyl)-4,5-diphenylimidazolidine-2-thione (S3h): The typical procedure using **S2h** (540 mg, 0.784 mmol), Et_3N (0.33 mL, 2.4 mmol), thiophosgen (66 μL, 0.72 mmol), CH_2Cl_2 (10 mL), and column chromatography (hexane/EtOAc 15:1) gave the title compound (440 mg, 77%) as pale orange amorphous of mp 145.0–147.0 °C: $[\alpha]_D^{23}$ +141 (*c* 1.25, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.38 (dd, *J* = 8.0, 6.0, 2H), 7.29–7.27 (m, 6H), 7.01–6.99 (m, 4H), 6.65 (td, *J* = 8.0, 2.5, 2H), 6.39 (dd, *J* = 8.0, 2.5, 2H), 5.45 (d, *J* = 15.5, 2H), 4.35 (s, 2H), 4.24 (d, *J* = 15.5, 2H), 0.71 (s, 18H), 0.05 (s, 6H), 0.00 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.4 (C), 163.4 (d, *J* = 245, C), 154.4 (d, *J* = 10, C), 138.7 (C), 129.6 (d, *J* = 9, CH), 129.1 (CH), 128.6 (CH), 126.7 (CH), 122.4 (C), 108.2 (d, *J* = 21, CH), 106.3 (d, *J* = 21, CH), 69.3 (CH), 42.4 (CH_2), 25.4 (CH_3), 17.9 (C), –4.5 (CH_3). **MS** (ESI) *m*/*z*: 731 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{53}N_2O_2F_2Si_2S$, 731.3334; found, 731.3328. **IR** (KBr): 2930, 2870, 1560, 1500, 1460, 1440, 1330, 1290, 1240, 1100.

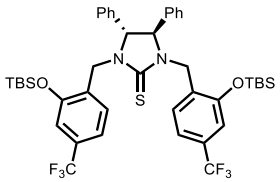


(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-bromobenzyl)-4,5-diphenylimidazolidine-2-thione (S3i): The typical procedure using **S2i** (530 mg, 0.655 mmol), Et_3N (0.30 mL, 2.3 mmol), thiophosgen (55 μL, 0.72 mmol), CH_2Cl_2 (10 mL), and column chromatography (hexane/EtOAc 15:1 to 10:1) gave the title compound as colorless solid of mp 165.8–166.6°C:

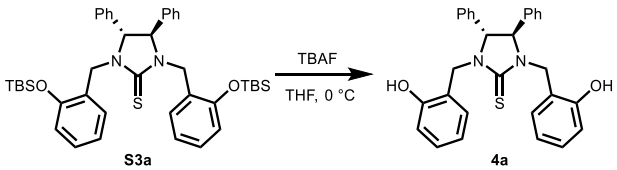
$[\alpha]_D^{23}$ +45.6 (*c* 1.24, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.30–7.27 (m, 8H), 7.06 (d, *J* = 8.0, 2.0, 2H), 7.01 (m, 4H), 6.82 (d, *J* = 2.0, 2H), 5.44 (d, *J* = 14.0, 2H), 4.37 (s, 2H), 4.23 (d, *J* = 14.0, 2H), 0.71 (s, 18H), 0.05 (s, 6H), 0.00 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.6 (C), 154.1 (C), 138.4 (C), 129.9 (CH), 129.2 (CH), 128.7 (CH), 126.7 (CH), 125.7 (C), 124.5 (CH), 122.0 (CH), 120.9 (C), 69.3 (CH), 42.5 (CH_2), 25.4 (CH_3), 17.9 (C), –4.4 (CH_3). **MS** (ESI) *m*/*z*: 851 (M + H), 853 (M + 2 + H), 855 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{53}N_2O_2Si_2SCl_2$, 851.1733; found, 851.1730. **IR** (NaCl): 2950, 2890, 1580, 1470, 1400, 1260, 1110, 950, 820, 770.



(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-iodobenzyl)-4,5-diphenylimidazolidine-2-thione (S3j): The typical procedure using **S2j** (440 mg, 0.487 mmol), Et_3N (0.33 mL, 2.4 mmol), thiophosgen (66 μL, 0.72 mmol), CH_2Cl_2 (10 mL), and column chromatography (hexane/EtOAc 15:1) gave the title compound (440 mg, 77%) as pale orange amorphous of mp 193.0–194.1 °C: $[\alpha]_D^{28}$ +10.3 (*c* 1.50, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.30–7.24 (m, 8H), 7.12 (d, *J* = 8.0, 2H), 7.01–6.99 (m, 6H), 5.45 (d, *J* = 14.0, 2H), 4.37 (s, 2H), 4.22 (d, *J* = 14.0, 2H), 0.70 (s, 18H), 0.05 (s, 6H), –0.02 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.6 (C), 154.1 (C), 138.4 (C), 130.5 (CH), 130.0 (CH), 129.2 (CH), 128.7 (CH), 127.9 (CH), 126.7 (CH), 126.5 (C), 92.2 (C), 69.4 (CH), 42.6 (CH_2), 25.4 (CH_3), 17.9 (C), –4.5 (CH_3). **MS** (ESI) *m*/*z*: 947 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{41}H_{53}N_2O_2Si_2SI_2$, 947.1456; found, 947.1441. **IR** (KBr): 2980, 2850, 1580, 1480, 1360, 1260, 1100, 930, 830, 780.

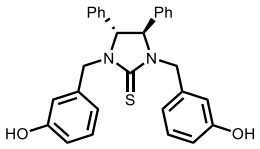


(*4R,5R*)-1,3-Bis(2-(*tert*-butyldimethylsiloxy)-4-trifluoromethylbenzyl)-4,5-diphenylimidazolidine-2-thione (S3k): The typical procedure using **S2k** (530 mg, 0.654 mmol), Et_3N (0.30 mL, 2.1 mmol), thiophosgen (60 μL, 0.76 mmol), and CH_2Cl_2 (15 mL) gave the title compound (420 mg, 73%) as pale yellow amorphous of mp132.8–133.8 °C: $[\alpha]_D^{23}$ +88.5 (*c* 1.13, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.52 (d, *J* = 8.0, 2H), 7.32–7.29 (m, 6H), 7.19 (d, *J* = 8.0, 2H), 7.04 (m, 4H), 6.90 (s, 2H), 5.52 (*J* = 16.0, 2H), 4.44 (s, 2H), 4.36 (d, *J* = 16.0, 2H), 0.74 (s, 18H), 0.09 (s, 6H), 0.00 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 183.9 (C), 153.5 (C), 138.2 (C), 130.7 (C), 130.4 (q, *J* = 32, C), 129.3 (CH), 128.9 (CH), 126.6 (CH), 123.5 (q, *J* = 270, C), 117.9 (CH), 117.9 (CH), 115.5 (CH), 69.7 (CH), 42.9 (CH_2), 25.4 (CH_3), 17.9 (C), –4.5 (CH_3). **MS** (ESI) *m*/*z*: 831 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{43}H_{53}N_2O_2F_6Si_2S$, 831.3271; found, 831.3306. **IR** (NaCl): 2930, 2840, 1630, 1420, 1340, 1250, 1125, 960, 840, 770.

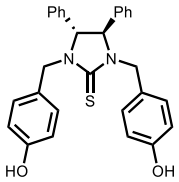


Typical Procedure for Deprotection of Chiral Lewis Base Catalyst. (4*R*,5*R*)-1,3-Bis(2-hydroxybenzyl)-4,5-diphenyl-imidazolidine-2-thione (4a): To a solution of **S3a** (100 mg, 0.144 mmol) in THF (10 mL), was added a 1.0 M THF solution

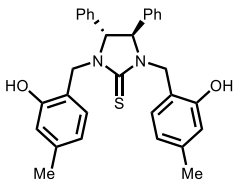
of TBAF (2.9 mL, 2.9 mmol) at 0 °C. The mixture was stirred for 30 min, and then sat NH_4Cl aq (30 mL) was added. The whole was extracted with Et_2O (20 mL × 3). The combined organic layers were washed with sat $NaHCO_3$ aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the title compound (60 mg, 90%) as colorless solid of mp 163.5–165.5 °C: $[\alpha]_D^{27}$ +301 (*c* 1.16, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.42 (brs, 2H), 7.33–7.30 (m, 6H), 7.17 (m, 2H), 7.01–6.94 (m, 6H), 6.69–6.61 (m, 4H), 5.52 (d, *J* = 15.0, 2H), 4.41 (s, 2H), 3.96 (d, *J* = 15.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 179.4 (C), 155.4 (C), 137.2 (C), 131.4 (CH), 130.1 (CH), 129.4 (CH), 129.1 (CH), 127.2 (CH), 119.8 (CH), 119.7 (C), 117.3 (CH), 70.0 (CH), 45.8 (CH_2). **MS** (ESI) *m*/*z*: 467 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{29}H_{27}N_2O_2S$, 467.1793; found, 467.1772. **IR** (KBr): 3744, 2914, 1490, 1425, 1348, 1289, 1217, 1092, 923, 749.



(4*R*,5*R*)-1,3-Bis(3-hydroxybenzyl)-4,5-diphenylimidazolidine-2-thione (4b): The typical procedure using **S3b** (100 mg, 0.144 mmol), THF (10 mL), a 1.0 M THF solution of TBAF (2.8 mL, 2.8 mmol), and column chromatography (hexane/EtOAc ═5:1 and then $CHCl_3$:MeOH ═1:5) gave the title compound (60.3 mg, 92%) as pale yellow amorphous of mp 94.0–95.5 °C: $[\alpha]_D^{23}$ +93.7 (*c* 1.50, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.27–7.24 (m, 6H), 7.08 (dd, *J* = 8.0, 7.0, 2H), 6.97 (m, 4H), 6.87 (s, 2H), 6.74 (d, *J* = 8.0, 2H), 6.66 (d, *J* = 7.0, 2H), 5.69 (d, *J* = 15.0, 2H), 4.43 (s, 2H), 3.78 (d, *J* = 15.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 182.2 (C), 156.0 (C), 137.9 (C), 137.6 (C), 129.8 (CH), 129.2 (CH), 128.8 (CH), 127.1 (CH), 120.6 (CH), 115.0 (CH), 114.9 (CH), 69.4 (CH), 48.3 (CH_2). **MS** (ESI) *m*/*z*: 467 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{29}H_{27}N_2O_2S$, 467.1793; found, 467.1772. **IR** (KBr): 3560, 2920, 1590, 1450, 1410, 1350, 1300, 1220, 1150, 960.

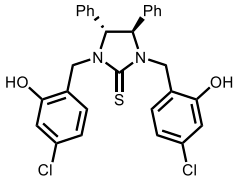


(4*R*,5*R*)-1,3-Bis(4-hydroxybenzyl)-4,5-diphenylimidazolidine-2-thione (4c): The typical procedure using **S3c** (79.8 mg, 0.115 mmol), THF (10 mL), a 1.0 M THF solution of TBAF (2.3 mL, 2.3 mmol), and column chromatography (hexane/EtOAc = 9:1 and then $CHCl_3$:MeOH = 1:9) gave the title compound (35.9 mg, 67%) as colorless amorphous of mp 176.0–178.2 °C: $[\alpha]_D^{23}$ +92.2 (*c* 0.668, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.30–7.23 (m, 6H), 7.08 (m, 4H), 6.93 (m, 4H), 6.74 (d, *J* = 8.0, 4H), 5.76 (d, *J* = 15.0, 2H), 4.27 (s, 2H), 3.69 (d, *J* = 15.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 182.0 (C), 155.3 (C), 138.1 (C), 129.9 (CH), 129.1 (CH), 128.7 (CH), 127.8 (C), 127.0 (CH), 115.4 (CH), 69.0 (CH), 48.3 (CH_2). **MS** (ESI) *m*/*z*: 467 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{29}H_{27}N_2O_2S$, 467.1793; found, 467.1772. **IR** (KBr): 3280, 3000, 2920, 1610, 1590, 1510, 1450, 1350, 1200, 1150.

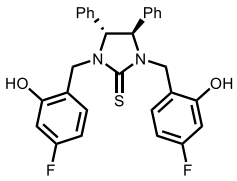


(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-methylbenzyl)-4,5-diphenylimidazolidine-2-thione (4f): The typical procedure using **S3f**

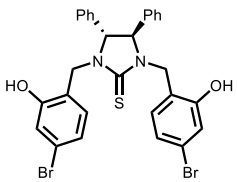
(49 mg, 0.068 mmol), THF (5 mL), a 1.0 M THF solution of TBAF (2.0 mL, 2.0 mmol), and column chromatography (hexane/EtOAc 4:1) gave the title compound (30 mg, 90%) as colorless solid of mp 133.4–145.0 °C: $[\alpha]_D^{30}$ +337 (*c* 1.00, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.40 (brs, 2H), 7.35–7.32 (m, 6H), 7.01 (m, 4H), 6.78 (s, 2H), 6.50–6.48 (m, 4H), 5.51 (d, *J* = 15.0, 2H), 4.41 (s, 2H), 3.87 (d, *J* = 15.0, 2H), 2.25 (s, 6H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 179.3 (C), 155.3 (C), 140.3 (C), 137.3 (C), 131.2 (CH), 129.4 (CH), 129.0 (CH), 127.3 (CH), 120.6 (CH), 117.9 (CH), 116.7 (C), 66.9 (CH), 45.7 (CH_2), 21.3 (CH_3). **MS** (ESI) *m*/*z*: 495 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{31}H_{31}N_2O_2S$, 495.2106; found, 495.2088. **IR** (NaCl): 3330, 2910, 1630, 1560, 1490, 1410, 1280, 1220, 940, 770.



(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-chlorobenzyl)-4,5-diphenylimidazolidine-2-thione (4g): The typical procedure using **S3g** (600 mg, 0.790 mmol), THF (30 mL), a 1.0 M THF solution of TBAF (15.0 mL, 15.0 mmol) and column chromatography (hexane/EtOAc 3:1 to 1:1) followed by recrystallization from CH_2Cl_2/hexane gave the title compound (208 mg, 49%) as colorless solid of mp 136.4–137.0 °C: $[\alpha]_D^{23}$ +251 (*c* 1.07, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.69 (brs, 2H), 7.38–7.32 (m, 6H), 7.00–6.95 (m, 6H), 6.64 (dd, *J* = 8.0, 2.0, 2H), 6.50 (d, *J* = 8.0, 2H), 5.39 (d, *J* = 12.0, 2H), 4.39 (s, 2H), 3.99 (d, *J* = 12.0, 2H).**^{13}C NMR** ($CDCl_3$, 100 MHz): 179.6 (C), 156.2 (C), 136.6 (C), 135.4 (C), 132.1 (CH), 129.5 (CH), 129.3 (CH), 127.1 (CH), 120.0 (CH), 118.3 (C), 117.7 (CH), 70.4 (CH), 45.4 (CH_2). **MS** (ESI) *m*/*z*: 535 (M + H), 537 (M + 2 + H), 539 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{29}H_{25}N_2O_2SCl_2$, 535.1014; found, 535.1011. **IR** (NaCl): 3220, 2910, 2870, 1600, 1490, 1400, 1200, 890, 740, 680.

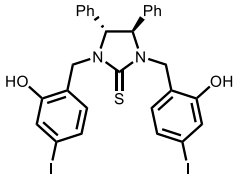


(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-fluorobenzyl)-4,5-diphenylimidazolidine-2-thione (4h): The typical procedure using **S3h** (440 mg, 0.602 mmol), THF (6 mL), a 1.0 M THF solution of TBAF (6.0 mL, 6.0 mmol), and column chromatography followed by recrystallization from CH_2Cl_2/hexane gave the title compound (220 mg, 73%) as beige powder of mp 139.4–140.4 °C: $[\alpha]_D^{30}$ +266 (*c* 1.08, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.73 (brs, 2H), 7.40–7.30 (m, 6H), 6.98 (m, 4H), 6.68 (dd, *J* = 8.0, 2.5, 2H), 6.52 (dd, *J* = 8.0, 7.5, 2H), 6.36 (dd, *J* = 8.0, 7.5, 2.5, 2H), 5.39 (d, *J* = 15.5, 2H), 4.39 (s, 2H), 4.00 (d, *J* = 15.5, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 179.5 (C), 163.5 (d, *J* = 245, C), 157.1 (d, *J* = 12, C), 136.8 (C), 132.2 (d, *J* = 10, CH), 129.5 (CH), 129.3 (CH), 127.1 (CH), 115.7 (C), 106.7 (d, *J* = 20, CH), 104.7 (d, *J* = 20, CH), 70.2 (CH), 46.0 (CH_2). **MS** (ESI) *m*/*z*: 535 (M + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{29}H_{25}N_2O_2F_2S$, 503.1605; found, 503.1602. **IR** (KBr): 3490, 3000, 2860, 1500, 1470, 1420, 1340, 1220, 1120, 800.

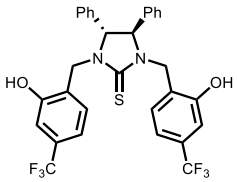


(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-bromobenzyl)-4,5-diphenylimidazolidine-2-thione (4i): The typical procedure using **S3i**

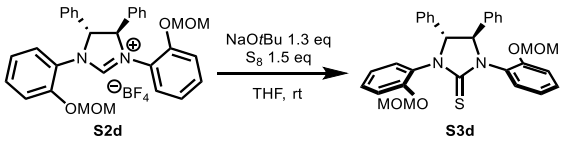
(250 mg, 0.293 mmol), THF (5 mL), a 1.0 M THF solution of TBAF (3.0 mL, 3.0 mmol), and column chromatography (hexane/EtOAc 1:20 to 1:1) gave brown oil (230 mg) including the title compound and impurity. The oil was dissolved in pyridine (1 mL) and Ac_2O (0.1 mL, 0.1 mmol), and the mixture was heated under reflux for 1 h. After the mixture was cooled to rt, the reaction was quenched by the addition of water. The aqueous layer was separated and extracted with EtOAc (5 mL × 3). The combined organic layers were washed with 2 M HCl aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the acetylated product (200 mg, quant) as colorless amorphous. The amorphous and K_2CO_3 (170 mg, 1.23 mmol) were suspended in MeOH (5 mL) and stirred at rt for 1 h. The mixture was diluted with Et_2O (5 mL) and poured into water (10 mL). The aqueous layer was separated and extracted with Et_2O (5 mL× 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the title compound (130 mg, 3 steps 72%) as colorless amorphous of mp 111.5–112.4 °C: $[\alpha]_D^{23}$ +83.4 (*c* 1.00, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.66 (s, 2H), 7.38–7.25 (m, 6H), 7.11 (d, *J* = 2.0, 2H), 6.99–6.96 (m, 4H), 6.78 (dd, *J* = 8.0, 2.0, 2H), 6.44 (d, *J* = 8.0, 2H), 5.38 (d, *J* = 16.0, 2H), 4.39 (s, 2H), 3.98 (d, *J* = 16.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 179.7 (C), 156.3 (C), 136.6 (C), 132.4 (CH), 129.5 (CH), 129.4 (CH), 127.2 (CH), 123.3 (C), 122.9 (CH), 120.6 (CH), 118.8 (C), 70.5 (CH), 45.5 (CH_2). **MS** (ESI) *m*/*z*: 623 (M + H), 625 (M + 2 + H), 625 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + K]^+$ calcd for $C_{29}H_{24}N_2O_2SBr_2K$, 660.9562; found, 660.9550. **IR** (KBr): 3400, 3000, 2920, 1600, 1480, 1430, 1410, 1220, 880, 700.



(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-iodobenzyl)-4,5-diphenylimidazolidine-2-thione (4j): The typical procedure using **S3j** (360 mg, 0.380 mmol), THF (10 mL), a 1.0 M THF solution of TBAF (6.0 mL, 6.0 mmol), and column chromatography (hexane/EtOAc 1:9 to 1:1) gave yellow oil (330 mg) including the title compound and impurity. The oil was dissolved in pyridine (1 mL) and Ac_2O (0.1 mL, 0.1 mmol), and the mixture was heated under reflux for 0.5 h. After the mixture was cooled to rt, the reaction was quenched by the addition of water. The aqueous layer was separated and extracted with EtOAc (5 mL × 3). The combined organic layers were washed with 2 M HCl aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 8:1 to 3:1) to give the acetylated product (260 mg, quant) as colorless amorphous. The amorphous and K_2CO_3 (140 mg, 1.01 mmol) were suspended in MeOH (10 mL) and stirred at rt for 0.5 h. The mixture was diluted with Et_2O (5 mL) and poured into water (10 mL). The aqueous layer was separated and extracted with Et_2O (5 mL× 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the title compound (99 mg, 3 steps 23%) as colorless amorphous of mp 144.0–145.5 °C: $[\alpha]_D^{23}$ +41.4 (*c* 1.28, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.50 (s, 2H), 7.26–7.20 (m, 8H), 6.89–6.86 (m, 6H), 6.19 (m, 2H), 5.27 (d, *J* = 15.0, 2H), 4.29 (s, 2H), 3.87 (d, *J* = 15.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 179.7 (C), 156.0 (C), 136.6 (C), 132.6 (CH), 129.5 (CH), 129.3 (CH), 128.9 (CH), 127.2 (CH), 126.5 (CH), 119.6 (C), 95.0 (C), 70.4 (CH), 45.6 (CH_2). **MS** (ESI) *m*/*z*: 719 (M + H). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd for $C_{29}H_{24}N_2O_2SI_2Na$, 740.9546; found, 740.9529. **IR** (NaCl): 3200, 3020, 2910, 1650, 1600, 1470, 1410, 1200, 880, 750, 700.

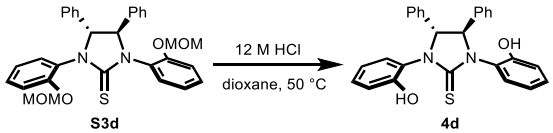


(4*R*,5*R*)-1,3-Bis(2-hydroxy-4-fluorobenzyl)-4,5-diphenylimidazolidine-2-thione (4k): The typical procedure using **S3k** (83.0 mg, 0.100 mmol), THF (3 mL), a 1.0 M THF solution of TBAF (1.0 mL, 1.0 mmol), and column chromatography (hexane/EtOAc 2:1) gave yellow oil (57 mg) including the title compound and impurity. The oil was dissolved in pyridine (1 mL) and Ac_2O (0.1 mL, 0.1 mmol), and the mixture was heated under reflux for 3 h. After the mixture was cooled to rt, the reaction was quenched by the addition of water. The aqueous layer was separated and extracted with EtOAc (5 mL × 3). The combined organic layers were washed with 2 M HCl aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 1:0, 5:1 and then 2:1) to give the acetylated product (50 mg, 77%) as colorless oil. The amorphous and K_2CO_3 (50 mg, 0.36 mmol) were suspended in MeOH (5 mL) and stirred at rt for 3 h. The mixture was diluted with Et_2O (5 mL) and poured into water (10 mL). The aqueous layer was separated and extracted with Et_2O (5 mL× 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 5:1) to give the title compound (34 mg, 3 steps 56 %) as beige oil: $[\alpha]_D^{30}$ +127 (*c* 1.11, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.80 (s, 2H), 7.37–7.25 (m, 6H), 7.18 (s, 2H), 6.99 (m, 4H), 6.90 (d, *J* = 8.0, 2H), 6.70 (d, *J* = 8.0, 2H), 5.40 (d, *J* = 15.0, 2H), 4.43 (s, 2H), 4.18 (d, *J* = 15.0, 2H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 180.0 (C), 155.7 (C), 136.5 (C), 132.3 (q, *J* = 32, C), 131.8 (CH), 129.6 (CH), 129.5 (CH), 127.0 (CH), 123.5 (q, *J* = 270, C), 123.4 (C), 116.4 (q, *J* = 5, CH), 114.5 (q, *J* = 5, CH), 70.7 (CH), 45.8 (CH_2). **MS** (ESI) *m*/*z*: 603 (M + H). **HRMS** (ESI) *m*/*z*: $[M + K]^+$ calcd for $C_{31}H_{24}N_2O_2SF_6K$, 641.1100; found, 641.1121. **IR** (NaCl): 3250, 3030, 2930, 1570, 1500, 1440, 1320, 1210, 1160, 740.



S2d **S3d**

(4*R*,5*R*)-1,3-Bis(2-(methoxymethoxy)phenyl)-4,5-diphenylimidazolidine-2-thione (S3d): A mixture of **S2d** (58 mg, 0.10 mmol), NaO*t*Bu (12 mg, 0.13 mmol), and S_8 (5.0 mg, 0.15 mmol) in THF (1.0 mL) was stirred for 3 h and then concentrated under reduced pressure. The resulting solids were dissolved in $CHCl_3$ and filtered through silica pad ($CHCl_3$). The filtrate was concentrated under reduced pressure to give the title compound as colorless solid of mp 144.5–145.1 °C: $[\alpha]_D^{28}$ –37.1 (*c* 0.450, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.43 (m, 4H), 7.36–7.31 (m, 6H), 7.20 (t, *J* = 8.0, 2H), 7.15 (d, *J* = 8.0, 2H), 7.08 (d, *J* = 8.0, 2H), 6.86 (t, *J* = 8.0, 2H), 5.34 (d, *J* = 6.5, 2H), 5.28 (d, *J* = 6.5, 2H), 5.17 (s, 2H), 3.54 (s, 6H). **^{13}C NMR** (acetone-d_6, 100 MHz): 184.3 (C), 153.7 (C), 140.0 (C), 132.4 (CH), 129.2 (C), 128.8 (CH), 128.7 (CH), 128.4 (CH), 127.8 (CH), 120.9 (CH), 115.0 (CH), 94.5 (CH_2), 73.0 (CH), 55.8 (CH_3). **MS** (ESI) *m*/*z*: 461 (M + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{31}H_{31}N_2O_4S$, 527.2005; found, 527.2029. **IR** (NaCl): 3066, 2913, 2846, 1508, 1260, 1080, 990, 750.

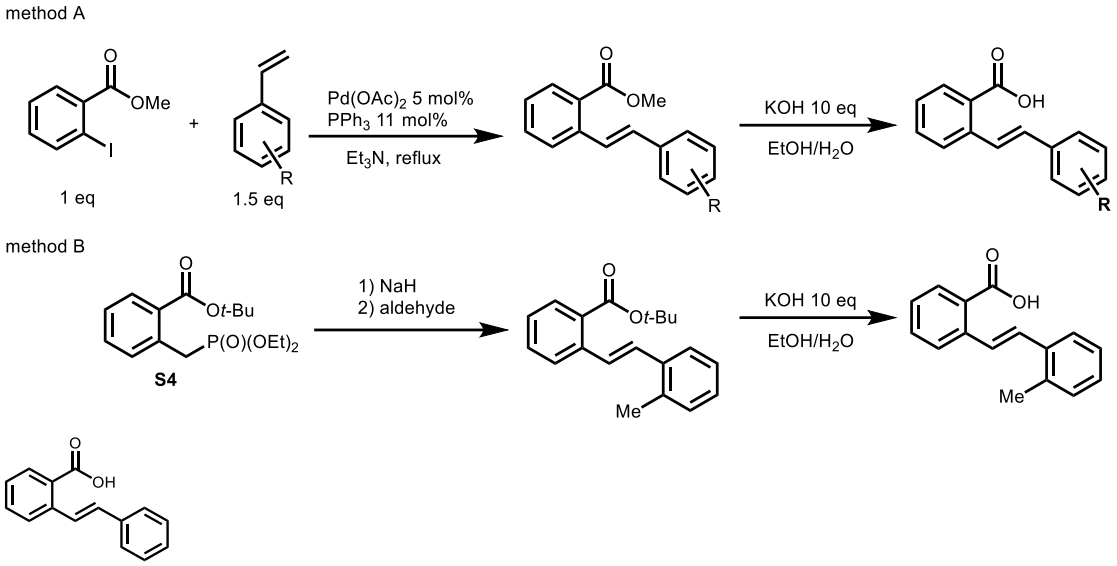


S3d **4d**

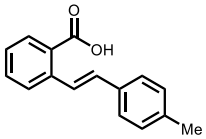
(4*R*,5*R*)-1,3-Bis(2-hydroxybenzyl)-4,5-diphenylimidazolidine-2-thione (4d): To a solution of **S3d** (58 mg, 0.10 mmol) in dioxane (5.0 mL) was added 12 M HCl (1.0 mL), and the mixture was heated at 50 ºC for 1 h. After colling to rt, the

mixture was concentrated under reduced pressure and purified by column chromatography (hexane/EtOAc 2:1) to give the title compound (40 mg, 2 steps 91 %) as colorless solid of mp 163.5–165.5 °C: $[\alpha]_D^{28}$ –140 (*c* 0.182, $CHCl_3$). **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.43–7.26 (m, 10H), 7.16 (td, *J* = 8.0, 1.0, 2H), 7.06–7.01 (m, 4H), 6.85 (td, *J* = 8.0, 1.0, 2H), 5.32 (s, 2H). **^{13}C NMR** (DMSO-d_6, 100 MHz): 183.1 (C), 153.9 (C), 139.6 (C), 132.2 (CH), 129.1 (CH), 128.9 (CH), 128.8 (CH), 128.1 (CH), 126.9 (C), 118.9 (CH), 116.8 (CH), 72.2 (CH). **MS** (ESI) *m*/*z*: 461 (M + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{27}H_{22}N_2O_2NaS$, 461.1300; found, 461.1296. **IR** (NaCl): 3300, 3040, 2980, 2360, 1497, 1324, 752, 700.

4. Preparation of Stilbenecarboxylic Acids

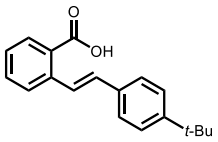


Typical Procedure A. (***E***)**-2-Styryl Benzoic Acid (1a)**: A mixture of methyl *o*-iodobenzoate (4.60 g, 17.6 mmol), styrene (2.5 mL, 21 mmol), triphenylphosphine (0.30 g, 1.2 mmol), palladium acetate (0.13 g, 0.58 mmol), and triethylamine (5.3 mL, 41 mmol) was heated at 100 °C for 12 h. After cooling to rt, the mixture was diluted with EtOAc (10 mL) and washed with 2 M HCl aq (20 mL). The aqueous layer was extracted with EtOAc (20 mL× 2). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by flash column chromatography (hexane/EtOAc 10:1) to give methyl (*E*)-2-styrylbenzoate (4.18 g, quant) as colorless oil. A mixture of the ester (4.16 g, 17.5 mmol), EtOH (30 mL), and 6 M KOH aq (4.5 mL, 27 mmol) was stirred at rt for 12 h. The mixture was diluted with water (20 mL) and washed with Et_2O. The ethereal layer was discarded, and the aqueous layer was acidified with 1 M HCl aq and extracted with Et_2O (20 mL × 2). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The resulting solids were recrystallized from hexane/EtOAc to give the title compound (2.58 g, 66 %) as a colorless solid of mp 159.5–161.0 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.10 (dd, *J* = 8.0, 1.0, 1H), 8.08 (d, *J* = 16.0, 1H), 7.76 (d, *J* = 7.5, 1H), 7.61–7.56 (m, 3H), 7.40–7.37 (m, 3H), 7.29 (td, *J* = 7.5, 1.0, 1H), 7.05 (d, *J* = 16.0, 1H). ^{1}H NMR was in agreement with that reported.[3)]

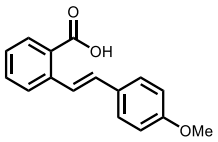


(*E*)-2-(4-Methylstyryl)benzoic Acid (1b): Typical procedure A using methyl *o*-iodobenzoate (560 mg, 2.20 mmol), *p*-methylstyrene (890 mg, 7.50 mmol), PPh_3 (140 mg, 0.534 mmol), $Pd(OAc)_2$ (56 mg, 0.25 mmol), and Et_3N (2.0 mL, 15 mmol) gave (*E*)-2-(*p*-methylstyryl)benzoate (470 mg, 1.86 mmol, 84%) as colorless oil. The ester was hydrolyzed using EtOH (10 mL) and 6 M KOH (1.5 mL, 9.0 mmol) gave the title compound (430 mg, 62%) as colorless solid of mp 153.1–154.3 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.11 (d, *J* = 7.5, 1H), 8.05 (d, *J* = 16.0, 1H), 7.76 (d, *J* = 7.5, 1H), 7.58 (t, *J* = 7.5, 1H), 7.48 (d, *J* = 8.0, 2H), 7.36 (t, *J* = 7.5, 1H), 7.19 (d, *J* = 8.0, 2H), 7.03 (d, *J* = 16.0, 1H), 2.39 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)]

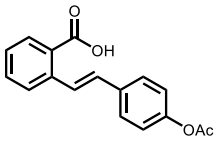
3) Chen, J.; Zhou, L.; Tan, C. K.; Yeung, Y.-Y. *J. Org. Chem.* **2012**, *77*, 999.



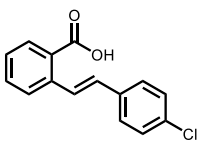
(*E*)-2-(4-(*tert*-Butyl)styryl)benzoic Acid (1c): Typical procedure A using methyl *o*-bromobenzoate (1.30 g, 6.00 mmol), *p*-*tert*-butylstyrene (1.64 g, 10.0 mmol), PPh_3 (160 mg, 0.600 mmol), $Pd(OAc)_2$ (67 mg, 0.30 mmol), and Et_3N (5.0 mL, 38 mmol) gave (*E*)-2-(*p*-*tert*-butylstyryl)benzoate (1.65 g, 5.60 mmol, 94%) as colorless solid. The ester was hydrolyzed using EtOH (10 mL) and 6 M KOH (4.0 mL, 24.0 mmol) gave the title compound (1.25 g, 80%) as colorless solid of mp 160.0–161.5 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.05 (dd, *J* = 8.0, 1.0, 1H), 8.00 (d, *J* = 16.0, 1H), 7.74 (d, *J* = 8.0, 1H), 7.56 (td, *J* = 8.0, 1.0, 1H), 7.50 (d, *J* = 8.5, 2H), 7.40 (d, *J* = 8.5, 1H), 7.34 (td, *J* = 8.0, 1.0, 2H), 7.02 (d, *J* = 16.0, 1H), 1.33 (s, 9H). ^{1}H NMR was in agreement with that reported.[4)]



(*E*)-2-(4-Methoxylstyryl)benzoic Acid (1d): Typical procedure A using methyl *o*-iodobenzoate (780 mg, 2.97 mmol), *p*-methoxystyrene (530 mg, 3.96 mmol), PPh_3 (60 mg, 0.22 mmol), $Pd(OAc)_2$ (24 mg, 0.11 mmol), and Et_3N (1.0 mL, 7.5 mmol) gave (*E*)-2-(*p*-methoxystyryl)benzoate (490 mg, 1.83 mmol, 60%) as yellow oil. The ester was hydrolyzed using EtOH (10 mL) and 6 M KOH (1.0 mL, 6.0 mmol) gave the title compound (230 mg, 50%) as yellow solid of mp 161.4–162.9 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.89−7.84 (m, 2H), 7.77 (d, *J* = 8.0, 1H), 7.54−7.45 (m, 3H), 7.30 (dt, *J* = 8.0, 1.0, 1H), 7.04 (d, *J* = 16.0, 1H), 6.91 (dd, *J* = 7.0, 2.0, 2H), 3.80 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)]

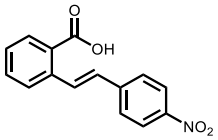


(*E*)-2-(4-Acetoxylstyryl)benzoic Acid (1e): Typical procedure A using *tert*-butyl *o*-iodobenzoate (780 mg, 2.97 mmol), *p*-acethoxystyrene (0.66 g, 5.0 mmol), PPh_3 (87 mg, 0.33 mmol), $Pd(OAc)_2$ (33 mg, 0.15 mmol), and Et_3N (5.0 mL, 39 mmol) gave (*E*)-2-(*p*-acethoxystyryl)benzoate (840 mg, 2.48 mmol, 82%) as yellow oil. The ester was hydrolyzed using DMSO (20 mL) and 6 M KOH (6.0 mL, 36 mmol) gave (*E*)-2-(4-hydroxystyryl)benzoic acid (400 mg, 94%) as pale yellow solid. The phenol was dissolved in pyridine (5 mL) and Ac_2O (5 mL, 5 mmol), and the mixture was stirred at rt for 23 h. The reaction was quenched with 2 M HCl aq (20 mL). The whole was extracted with EtOAc (5 mL × 3). The combined organic layers were washed with 2 M HCl aq and brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 4:1 to 1:1) to give the title compound (355 mg, 1.25 mmol) as colorless solid of mp 133.8–135.1 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.06 (d, *J* = 8.0, 1H), 8.00 (d, *J* = 16.0, 1H), 7.71 (d, *J* = 8.0, 1H), 7.58–7.54 (m, 3H), 7.36 (t, *J* = 8.0, 1H), 7.09 (d, *J* = 8.0, 2H), 7.00 (d, *J* = 16.0, 1H), 2.31 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)]

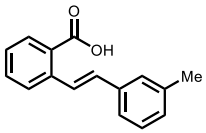


4) Triandafillidi, I.; Raftopoulou, M.; Savvidou, A.; Kokotos, C. G. *ChemCatChem* **2017**, *9*, 4120.

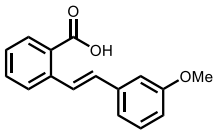
(*E*)-2-(4-Chlorostyryl)benzoic Acid (1f): Typical procedure A using methyl *o*-iodobenzoate (705 mg, 2.69 mmol), *p*-chlorostyrene (500 mg, 3.62 mmol), PPh_3 (53 mg, 0.20 mmol), $Pd(OAc)_2$ (22 mg, 95 μmol), and Et_3N (1.0 mL, 7.5 mmol) gave (*E*)-2-(*p*-chlorostyryl)benzoate (720 mg, 2.64 mmol, 98%) as colorless solid. The ester was hydrolyzed using EtOH (5 mL) and 6 M KOH (1.0 mL, 6.0 mmol) gave the title compound (453 mg, 66%) as pale yellow solid of mp 141.8–142.3 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.12 (d, *J* = 7.5, 1H), 8.05 (d, *J* = 16.5, 1H), 7.73 (d, *J* = 7.5, 1H), 7.58 (t, *J* = 7.5, 1H), 7.48 (d, *J* = 8.0, 2H), 7.41−7.32 (m, 3H), 6.97 (d, *J* = 16.5, 1H). ^{1}H NMR was in agreement with that reported.[3)]



(*E*)-2-(4-Nitrostyryl)benzoic Acid (1g): Typical procedure A using methyl *o*-iodobenzoate (1.00 g, 3.96 mmol), *p*-nitrostyrene (770 mg, 5.16 mmol), PPh_3 (77 mg, 0.30 mmol), $Pd(OAc)_2$ (31 mg, 0.14 mmol), and Et_3N (2.0 mL, 15 mmol) gave (*E*)-2-(*p*-nitrostyryl)benzoate (680 mg, 2.40 mmol, 67%) as yellow oil. The ester was hydrolyzed using EtOH (10 mL) and 9 M KOH (2.0 mL, 18 mmol) gave the title compound (390 mg, 50%) as yellow solid of mp 199.1–200.8 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.14 (d, *J* = 7.5, 1H), 8.05–7.99 (m, 2H), 7.85 (d, *J* = 7.5, 1H), 7.79 (d, *J* = 7.5, 1H), 7.62 (t, *J* = 7.5, 2H), 7.52–7.41 (m, 3H). ^{1}H NMR was in agreement with that reported.[3)]

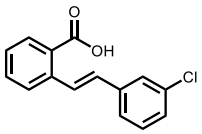


(*E*)-2-(3-Methylstyryl)benzoic Acid (1h): Typical procedure A using methyl *o*-iodobenzoate (1.26 g, 5.00 mmol), *m*-methylstyrene (890 mg, 7.50 mmol), PPh_3 (57 mg, 0.22 mmol), $Pd(OAc)_2$ (22 mg, 0.10 mmol), and Et_3N (1.0 mL, 7.5 mmol) gave (*E*)-2-(*m*-methylstyryl)benzoate (470 mg, 1.86 mmol, 84%) as colorless oil. The ester was hydrolyzed using EtOH (10 mL) and 5 M KOH (2.0 mL, 10 mmol) gave the title compound (140 mg, 30%) as pink powder of mp 163.0–164.2 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.06 (dd, *J* = 7.5, 1.0, 1H), 8.02 (d, *J* = 16.0, 1H), 7.73 (dd, *J* = 8.0, 1.0, 1H), 7.55 (ddd, *J* = 8.0, 7.5, 1.0, 1H), 7.37–7.33 (m, 3H), 7.24 (dd, *J* = 8.0, 7.5, 1H), 7.09 (dd, *J* = 8.0, 1.0, 1H), 7.00 (d, *J* = 16.0, 1H), 2.37 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)]

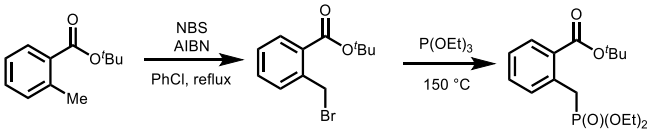


(*E*)-2-(3-Methoxystyryl)benzoic Acid (1i): Typical procedure A using methyl *o*-iodobenzoate (1.2 g, 5.0 mmol), *m*-methoxylstyrene (1.0 g, 7.6 mmol), PPh_3 (0.14 g, 0.54 mmol), $Pd(OAc)_2$ (56 mg, 0.25 mmol), and Et_3N (10 mL, 75 mmol) gave (*E*)-2-(*m*-methylstyryl)benzoate (1.0 g, 3.7 mmol, 75%) as colorless oil. The ester was hydrolyzed using EtOH (10 mL) and 6 M KOH (2.0 mL, 12 mmol) gave the title compound (270 mg, 30%) as colorless solid of mp 244.1–245.5 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.06 (dd, *J* = 7.5, 1.0, 1H), 8.02 (d, *J* = 16.0, 1H), 7.75 (d, *J* = 8.0, 1H), 7.58 (td, *J* = 8.0, 1.0, 1H), 7.36 (td, *J* = 8.0, 1.0, 1H), 7.29 (d, *J* = 8.0, 1H), 7.16 (d, *J* = 8.0, 1H), 7.08 (m, 1H), 7.00 (d, *J* = 16.0, 1H), 6.85 (dd, *J* = 8.0, 1.0, 1H), 3.84 (s, 3H). ^{1}H NMR was in agreement with that reported.[5)]

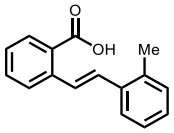
5) Noda, M. *Chem. Pharm. Bull.* **1998**, *46*, 1157.



(*E*)-2-(3-Chlorostyryl)benzoic Acid (1j): Typical procedure A using methyl *o*-iodobenzoate (1.00 g, 3.81 mmol), *m*-chlorostyrene (760 mg, 5.50 mmol), PPh_3 (82 mg, 0.32 mmol), $Pd(OAc)_2$ (33 mg, 0.14 mmol), and Et_3N (1.0 mL, 7.5 mmol) gave (*E*)-2-(*m*-chlorostyryl)benzoate (340 mg, 1.23 mmol, 30%) as colorless solid. The ester was hydrolyzed using EtOH (5 mL) and 6 M KOH (1.0 mL, 6.0 mmol) gave the title compound (300 mg, 93%) as colorless solid of mp 144.5–146.5 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.07 (d, *J* = 8.0, 1H), 8.04 (d, *J* = 16.0, 1H), 7.71 (d, *J* = 8.0, 1H), 7.57 (t, *J* = 8.0, 1H), 7.51 (m, 1H), 7.45−7.36 (m, 2H), 7.31−7.23 (m, 2H), 6.94 (d, *J* = 16.0, 1H). ^{1}H NMR was in agreement with that reported.[3)]



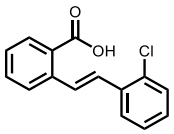
***tert*-Butyl 2-[(diethoxyphosphoryl)methyl]benzoate (S4)**: To a solution of *tert*-butyl *o*-methylbenzoate (1.17 g, 7.80 mmol) and *N*-bromosuccinimide (1.45 g, 8.20 mmol) in PhCl (20 mL) was added AIBN (64 mg, 0.40 mmol) at rt. The mixture was heated under reflux for 2 h, cooled to rt, and filtered through silica pad (hexane/EtOAc 20:1). The filtrate was concentrated under reduced pressure to give *tert*-butyl *o*-(bromomethyl)benzoate as a yellow oil. A mixture of the ester (1.59 g, 6.94 mmol) and triethyl phosphite (7.0 mL, 40 mmol) was stirred at 150 °C for 3 h, cooled to rt, and concentrated under reduced pressure. The crude mixture was purified by column chromatography (EtOAc) to afford the title compound as a yellow oil (1.42 g, 72%): **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.86 (d, *J* = 8.0, 1H), 7.44−7.38 (m, 2H), 7.29 (t, *J* = 8.0, 1H), 4.00 (m, 4H), 3.80 (d, *J* = 23.0, 2H), 1.61 (s, 9H), 1.22 (t, *J* = 7.0, 6H). ^{1}H NMR was in agreement with that reported.[6)] This compound was used next reaction without further purification.



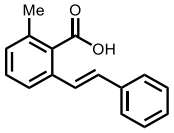
Typical Procedure B. **(*E*)-2-(2-Methylstyryl)benzoic Acid (1k)**: To a mixture of phosphonate **S4** (2.00 g, 7.02 mmol) in THF (50 mL) was added NaH (60 % in oil, 0.56 g, 14 mmol) at 0 °C. After 30 min, *o*-tolaldehyde (750 mg, 4.67 mmol) was added to the mixture at 0 °C. The mixture was heated at 70 °C with continuous stirring for 11 h. After cooled to rt, sat NH_4Cl aq was added. The whole was extracted with EtOAc (30 mL × 2). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexane/EtOAc 20:1) to give *tert*-butyl (*E*)-2-(*o*-methylstyryl)benzoate (1.12 g, 4.20 mmol, 90%) as colorless oil. A mixture of the ester (1.12 g, 4.20 mmol), EtOH (20 mL), and 6 M KOH aq (7.0 mL, 42 mmol) was stirred at rt for 48 h. The mixture was diluted with water (20 mL), and washed with CH_2Cl_2. The organic layer was discarded, and the aqueous layers were acidified with 1 M HCl aq and extracted with CH_2Cl_2 (20 mL × 2). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The resulting solids were recrystallized from hexane/EtOAc to give the title compound (580 mg, 57 %) as a colorless powder of mp 173.0–175.2 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.09 (dd, *J* = 8.0, 1.0, 1H), 7.93 (d, *J* = 16.0, 1H), 7.74 (d, *J* = 8.0, 1H), 7.67 (m, 1H), 7.59 (td, *J* = 8.0, 1.0, 1H), 7.31 (td, *J* = 8.0,

6) Baird, L. J.; Colomban, C.; Turner, P. H.; Teesdale-Spittle, J. E.; Harvey, J. E. *Org. Biomol. Chem.*, **2011**, *9*, 4432.

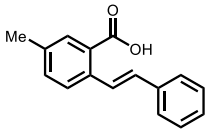
1.0, 1H), 7.20–7.18 (m, 4H), 2.45 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)]



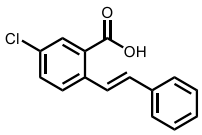
(*E*)-2-(2-Chlorostyryl)benzoic Acid (1l): Typical procedure A using methyl *o*-iodobenzoate (900 mg, 3.43 mmol), *o*-chlorostyrene (730 mg, 5.28 mmol), PPh_3 (82 mg, 0.32 mmol), $Pd(OAc)_2$ (33 mg, 0.14 mmol), and Et_3N (1.0 mL, 7.5 mmol) gave (*E*)-2-(*o*-chlorostyryl)benzoate (760 mg, 2.79 mmol, 81%) as yellow oil. The ester was hydrolyzed using EtOH (10 mL) and 9 M KOH (2.0 mL, 18 mmol) to give the title compound (390 mg, 50%) as colorless solid of mp 176.2–176.9 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.13 (d, *J* = 7.5, 1H), 8.06 (d, *J* = 16.5, 1H), 7.79 (t, *J* = 8.5, 2H), 7.62 (t, *J* = 7.5, 1H), 7.45−7.39 (m, 3H), 7.31−7.20 (m, 2H). ^{1}H NMR was in agreement with that reported.[3)]



(*E*)-2-Methyl-6-styrylbenzoic Acid (1m): Typical procedure A using methyl 2-bromo-6-methylbenzoate (450 mg, 2.00 mmol), styrene (270 mg, 2.59 mmol), PPh_3 (37 mg, 0.14 mmol), $Pd(OAc)_2$ (16 mg, 70 µmol), and Et_3N (5.0 mL, 38 mmol) gave (*E*)-2-methyl-6-styrylbenzoate (250 mg, 50%) as colorless oil. The ester was hydrolyzed using DMSO (5.0 mL) and 5 M KOH (1.0 mL, 5.0 mmol) to give the title compound (220 mg, 91%) as colorless solid of mp 102.2–103.6 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.55 (d, *J* = 8.0, 1H), 7.49 (d, *J* = 8.0, 2H), 7.36–7.32 (m, 4H), 7.27 (d, *J* = 8.0, 1H), 7.16 (d, *J* = 8.0, 1H), 7.08 (d, *J* = 16.0, 1H), 2.44 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 175.5 (C), 137.1 (C), 135.9 (C), 135.7 (C), 131.8 (CH), 131.8 (C), 130.2 (CH), 129.6 (CH), 128.7 (CH), 128.0 (CH), 126.8 (CH), 125.8 (CH), 123.4 (CH), 20.2 (CH_3). **MS** (ESI) *m*/*z*: 237 (M – H). **HRMS** (ESI) *m*/*z*: $[M - H]^-$ calcd for $C_{16}H_{13}O_2$, 237.0916; found, 237.0913. **IR (NaCl)**: 3030, 2905, 2340, 1695, 1580, 1382, 1286, 1130, 960.

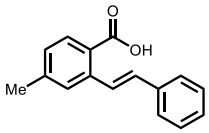


(*E*)-5-Methyl-2-styrylbenzoic Acid (1n): Typical procedure A using methyl 2-bromo-5-methylbenzoate (1.00 g, 4.65 mmol), styrene (630 mg, 6.05 mmol), PPh_3 (120 mg, 0.458 mmol), $Pd(OAc)_2$ (50 mg, 0.23 mmol), and Et_3N (5.0 mL, 38 mmol) gave (*E*)-5-methyl-2-styrylbenzoate (740 mg, 63%) as colorless oil. The ester was hydrolyzed using EtOH (5.0 mL) and 5 M KOH (1.8 mL, 9.0 mmol) gave the title compound (400 mg, 57%) as colorless solid of mp 149.7–151.5 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.02 (d, *J* = 16.0, 1H), 7.89 (s, 1H), 7.65 (d, *J* = 8.0, 1H), 7.54 (d, *J* = 8.0, 2H), 7.39–7.34 (m, 3H), 7.28 (d, *J* = 8.0, 1H), 7.00 (d, *J* = 16.0, 1H), 2.41 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 173.5 (C), 137.5 (C), 137.4 (C), 137.2 (C), 134.0 (CH), 132. (CH), 131.0 (CH), 128.7 (CH), 127.7 (CH), 127.4 (CH), 127.2 (CH), 127.1 (C), 126.8 (CH), 21.0 (CH_3). **MS** (ESI) *m*/*z*: 237 (M – H). **HRMS** (ESI) *m*/*z*: $[M - H]^-$ calcd for $C_{15}H_{10}O_2Cl$, 257.0369; found, 257.0363. **IR** (NaCl): 3030, 2916, 2360, 2341, 1680, 1490, 1350, 1277, 1248, 966, 750.



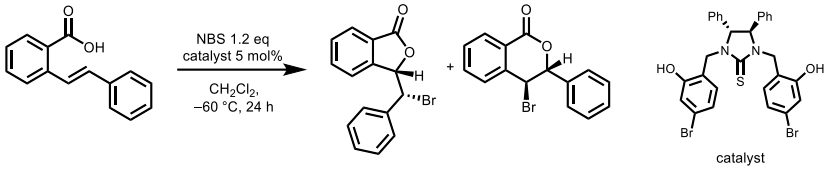
(*E*)-5-chloro-2-strylbenzoic acid (1o): Typical procedure A using *tert*-butyl 2-bromo-5-chlorobenzoate (698 mg, 2.40

mmol), styrene (324 mg, 3.12 mmol), PPh_3 (26 mg, 96 µmol), $Pd(OAc)_2$ (11 mg, 48 µmol), and Et_3N (5.0 mL, 38 mmol) gave *tert*-butyl (*E*)-5-chloro-2-styrylbenzoate (330 mg, 69%) as colorless oil. The ester was hydrolyzed using DMSO (5.0 mL) and 5 M KOH (1.1 mL, 5.0 mmol) to give the title compound (20 mg, 69%) as colorless solid of mp 147.0–147.5 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.02 (d, *J* = 7.5, 1H), 7.98 (d, *J* = 16.0, 1H), 7.68 (d, *J* = 8.0, 1H), 7.53–7.52 (m, 3H), 7.35 (t, *J* = 8.0, 2H), 7.28 (d, *J* = 8.0, 1H), 7.00 (d, *J* = 16.0, 1H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 172.0 (C), 138.6 (C), 136.9 (C), 133.1 (CH), 133.0 (C), 132.4 (CH), 131.4 (CH), 128.7 (CH), 128.6 (CH), 128.4 (C), 128.1 (CH), 126.9 (CH), 126.2 (CH). **MS** (ESI) *m*/*z*: 257 (M – H), 259 (M + 2 – H). **HRMS** (ESI) *m*/*z*: $[M - H]^-$ calcd for $C_{15}H_{10}O_2Cl$, 257.0369; found, 257.0363. **IR** (NaCl): 3050, 2917, 2360, 2341, 1693, 1477, 1411, 1296, 1240, 1112, 964.

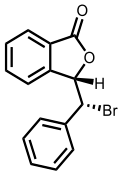


(*E*)-4-Methyl-2-styrylbenzoic acid (1p): Typical procedure A using methyl 2-bromo-4-methylbenzoate (400 mg, 1.75 mmol), styrene (240 mg, 2.28 mmol), PPh_3 (46 mg, 0.17 mmol), $Pd(OAc)_2$ (20 mg, 88 µmol), and Et_3N (5.0 mL, 38 mmol) gave (*E*)-4-methyl-2-styrylbenzoate (570 mg, quantity) as colorless oil. The ester was hydrolyzed using EtOH (10 mL) and 5 M KOH (1.0 mL, 5.0 mmol) to give the title compound (140 mg, 32%) as colorless solid of mp 188.7–190.1 °C: **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.06 (d, *J* = 16.0, 1H), 7.98 (d, *J* = 8.0, 1H), 7.56–7.54 (m, 3H), 7.36 (t, *J* = 7.5, 2H), 7.28 (d, *J* = 7.5, 1H), 7.17 (d, *J* = 8.0, 1H), 7.01 (d, *J* = 16.0, 1H), 2.45 (s, 3H). **^{13}C NMR** (*d*-acetone, 100 MHz): 167.8 (C), 142.5 (C), 139.1 (C), 137.8 (C), 131.0 (CH), 130.6 (CH), 128.6 (CH), 127.9 (CH), 127.6 (CH), 127.2 (CH),126.67 (CH) 126.66 (CH), 126.2 (C), 20.5 (CH_3). **MS** (ESI) *m*/*z*: 237 (M – H). **HRMS** (ESI) *m*/*z*: $[M - H]^-$ calcd for $C_{16}H_{13}O_2$, 237.0916; found, 237.0909. **IR (**NaCl**)**: 2916, 2848, 2360, 2341, 1673, 1301, 1241, 944.

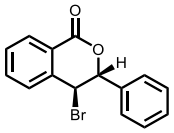
5. Enantioselective Bromolactonization of 1.



Typical Procedure. **(*S*)-3-[(*R*)-Bromo(phenyl)methyl]isobenzofuran-1(3*H*)-one (2a) and (3*R*,4*S*)-4-Bromo-3,4-dihydro-3-phenylisochromen-1-one (3a)**: Carboxylic acid **1a** (21.4 mg, 0.100 mmol) and catalyst **4i** (3.0 mg, 50 μmmol) were placed in a 10-mL tube and dissolved in CH_2Cl_2 (2.0 mL), and the mixture was cooled at –60 °C. After 10 min, *N*-bromosuccinimide (21.2 mg, 0.120 mmol) was added, and the mixture was stirred at −60 °C for 72 h. 2-Methyl-2-butene (0.1 mL) and sat $Na_2S_2O_3$ were added to the mixture at a 10 min interval, and the mixture was warmed to rt. The whole was extracted with CH_2Cl_2 (2 mL × 3). The combined organic layers were dried over Na_2SO_4 and concentrated under reduced pressure. The ratio of **2a** and **3a** was determined to be 8:1 on the basis of the integral area of ^{1}H NMR signals at 5.23 and 5.59 ppm in the crude mixture. The crude mixture was purified by column chromatography (hexane/EtOAc 5:1) to give an 8:1 mixture of **2a** and **3a** (28.0 mg, 90%) as a colorless solid. The isomers were separated by additional column chromatography (hexane/EtOAc 10:1) for characterization.



2a: Colorless solid of mp 121.1−122.0 °C. $[\alpha]_D^{20}$ –21.2 (*c* 0.782, $CHCl_3$) for 92:8 er; lit: $[\alpha]_D^{20}$ −5.8 (*c* 0.35, $CHCl_3$) for 57:43 er.[7] **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.84 (d, *J* = 7.5, 1H), 7.67–7.52 (m, 3H), 7.40 (m, 2H), 7.34−7.28 (m, 3H), 5.94 (d, *J* = 6.0, 1H), 5.23 (d, *J* = 6.0, 1H). ^{1}H NMR was in agreement with that reported.[7] The enantiomer ratio (er) was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:2, 0.6 mL/min, 220 nm, 40 °C, retention time = 19.3 min (3*R*,α*S*) and 22.1 min (3*S*,α*R*)).

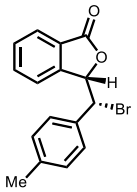


3a: Colorless oil. $[\alpha]_D^{20}$ +2.34 (*c* 0.211, $CHCl_3$) for 56:44 er; lit: $[\alpha]_D^{26}$ −70.2 (*c* 1.0, $CHCl_3$) for the other enantiomer with 92% ee.[3] **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.18 (d, *J* = 7.5, 1H), 7.62 (m, 1H), 7.52–7.49 (m, 2H), 7.37–7.29 (m, 5H), 5.94 (d, *J* = 4.5, 1H), 5.59 (d, *J* = 4.5, 1H). ^{1}H NMR was in agreement with that reported.[3] The er was determined by HPLC (Daicel Chiralcel OJ, *i*-PrOH/hexane 1:4, 1.0 mL/min, 220 nm, 40 °C, retention time = 18.4 min (3*R*,4*S*) and 19.8 min (3*S*,4*R*)).

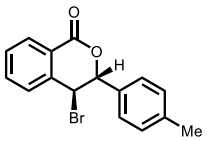
(*S*)-3-[(*R*)-Bromo(4-methylphenyl)methyl]isobenzofuran-1(3*H*)-one (2b) and (3*R*,4*S*)-4-Bromo-3-(4-methylphenyl)-3,4-dihydroisochromen-1-one (3b): The typical procedure using **1b** (24.0 mg, 0.100 mmol) gave a 5:2 mixture of **2b** and **3b** (29.8 mg, 93%) as a colorless oil. The ratio of **2b** and **3b** was determined on the basis of the integral area of ^{1}H NMR signals at 5.20 and 5.54 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc

7) Armstrong, A.; Braddock, D, C.;1 Jones, A, X.; Clark, S. *Tetrahedron Lett.* **2013**, *54*, 7004.

10:1) for characterization.

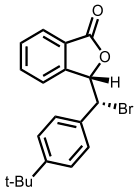


2b: Colorless solid of mp 161.0−161.9 °C. $[\alpha]_D^{24}$ –16.0 (*c* 1.50, $CHCl_3$) for 94:6 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.83 (d, *J* = 7.5, 1H), 7.67–7.60 (m, 2H), 7.54 (t, *J* = 7.5, 1H), 7.29 (d, *J* = 8.0, 2H), 7.12 (d, *J* = 8.0, 2H), 5.93 (d, *J* = 6.0, 1H), 5.20 (d, *J* = 6.0, 1H), 2.32 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.3 (C), 146.4 (C), 139.0 (C), 133.8 (CH), 133.0 (C), 129.9 (CH), 129.3 (CH), 128.4 (CH), 126.7 (C), 125.8 (CH), 123.8 (CH), 82.6 (CH), 53.5 (CH), 21.2 (CH_3). **MS** (ESI) *m*/*z*: 317 (M + H), 319 (M + 2 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{16}H_{14}O_2Br$, 317.0177; found, 317.0179. **IR** (NaCl): 3050, 2940, 2846, 1766, 1609, 1513, 1294, 1047, 749, 636. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 16.0 min (3*R*,α*S*) and 17.4 min (3*S*,α*R*)). The Absolute stereochemistry was determined (3*S*,α*R*) by X-ray crystallography analysis, for which suitable single crystal was obtained by slow evaporation of a solution in hexane/EtOAc.. The crystal data of **3b** are as follows; space group, $P4_3$; *a* = 8.67730 (1), *b* = 8.67730 (1), *c* = 17.8920 (5); *V* = 1347.19, *Z* = 4, *D*x = 1.564.[8)]



3b: Cololess oil. $[\alpha]_D^{24}$ +2.32 (*c* 0.525, $CHCl_3$) for 52:48 er; lit: $[\alpha]_D^{28}$ −73.4 (*c* 1.0, $CHCl_3$) for the other enantiomer with 83% ee.[3)] **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.15 (dd, *J* = 7.5, 1.0, 1H), 7.59 (td, *J* = 7.5, 1.0, 1H), 7.49–7.45 (m, 2H), 7.16–7.11 (m, 4H), 5.88 (d, *J* = 4.5, 1H), 5.54 (d, *J* = 4.5, 1H), 2.30 (s, 3H). ^{1}H NMR was in agreement with that reported.[3)] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:9, 0.6 mL/min, 220 nm, 40 °C, retention time = 17.5 min (3*R*,4*S*) and 20.0 min (3*S*,4*R*)).

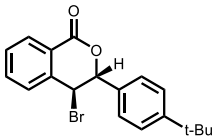
(*S*)-3-[(*R*)-Bromo(4-*tert*-butylphenyl)methyl]isobenzofuran-1(3*H*)-one (2c) and (3*R*,4*S*)-4-Bromo-3-(4-*tert*-butylphenyl)-3,4-dihydroisochromen-1-one (3c): The typical procedure using **1c** (28.0 mg, 0.100 mmol) gave a 1:1 mixture of **2c** and **3c** (33.1 mg, 92%) as a colorless oil. The ratio of **2c** and **3c** was determined on the basis of the integral area of ^{1}H NMR signals at 5.18 and 5.54 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.



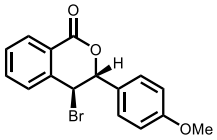
2c: Colorless solid of mp 117.3−118.1 °C. $[\alpha]_D^{24}$ –14.1 (*c* 0.938, $CHCl_3$) for 91:9 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.84 (d, *J* = 7.5, 1H), 7.65–7.64 (m, 2H), 7.54 (m, 1H), 7.34 (m, 4H), 5.92 (d, *J* = 7.0, 1H), 5.18 (d, *J* = 7.0, 1H), 1.29 (s, 9H). **^{13}C**

[8] CCDC 2189245 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/structures.

NMR ($CDCl_3$, 100 MHz): 169.3 (C), 152.1 (C), 146.4 (C), 133.8 (CH), 133.2 (C), 129.9 (CH), 128.2 (CH), 126.7 (C), 125.7 (CH), 125.6 (CH) 124.0 (CH), 82.4 (CH), 53.6 (CH), 34.6 (C), 31.2 (CH_3). **MS** (ESI) *m*/*z*: 381 (M + Na), 383 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd for $C_{19}H_{19}O_2NaBr$, 381.0466; found, 381.0468. **IR** (NaCl): 3026, 2963, 2868, 1770, 1610, 1466, 1360, 1285, 1061, 752. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:29, 0.6 mL/min, 220 nm, 40 °C, retention time = 18.0 min (3*R*,α*S*) and 19.5 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.

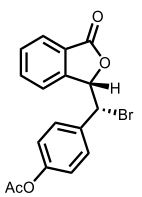


3c: Cololess solid of mp 117.4−118.0 °C. $[\alpha]_D^{28}$ +3.16 (*c* 1.00, $CHCl_3$) for 53:47 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.15 (dd, *J* = 7.5, 1.0, 1H), 7.59 (td, *J* = 7.5, 1.0, 1H), 7.49–7.45 (m, 2H), 7.16–7.11 (m, 4H), 5.88 (d, *J* = 4.5, 1H), 5.54 (d, *J* = 4.5, 1H), 2.30 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 163.1 (C), 152.0 (C), 137.9 (C), 134.5 (CH), 133.3 (C), 130.3 (CH), 129.8 (CH), 128.4 (CH), 126.1 (CH), 125.7 (CH), 124.2 (C), 84.1 (CH), 46.0 (CH), 34.6 (C), 21.1 (CH_3). **MS** (ESI) *m*/*z*: 381 (M + Na), 383 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{19}H_{20}O_2Br$, 359.0647; found, 359.0651. **IR** (NaCl): 2963, 2868, 1730, 1460, 1370, 1236, 1110, 1049, 764. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 254 nm, 40 °C, retention time = 15.4 min (3*R*,4*S*) and 16.0 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.



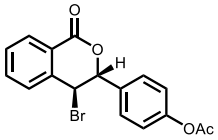
(3*SR*,4*RS*)-4-Bromo-3-(4-methoxyphenyl)-3,4-dihydroisochromen-1-one (3d): The typical procedure using **1d** (25.4 mg, 0.100 mmol) gave **3d** (25.8 mg, 77%) as a colorless oil in 50:50 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.14 (dd, *J* = 7.0, 1.5, 1H), 7.60 (td, *J* = 7.0, 1.5, 1H), 7.50–7.47 (m, 2H), 7.18 (d, *J* = 8.5, 2H), 6.83 (d, *J* = 8.5, 2H), 5.84 (d, *J* = 5.0, 1H), 5.52 (d, *J* = 5.0, 1H), 3.77 (s, 3H). ^{1}H NMR was in agreement with that reported.[3] The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:5, 0.6 mL/min, 220 nm, 40 °C, retention time = 18 min and 20 min).

(*S*)-3-[(*R*)-Bromo(4-acetoxyphenyl)methyl]isobenzofuran-1(3*H*)-one (2e) and (3*R*,4*S*)-4-Bromo-3-(4-acetoxyphenyl)-3,4-dihydroisochromen-1-one (3e): The typical procedure using **1e** (28.0 mg, 0.100 mmol) gave a 1:1 mixture of **2e** and **3e** (30.3 mg, 84% as a colorless oil. The ratio of **2e** and **3e** was determined on the basis of the integral area of ^{1}H NMR signals at 5.20 and 5.31 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.



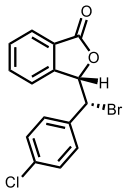
2e: Colorless solid of mp 131.1−131.8 °C. $[\alpha]_D^{24}$ –5.42 (*c* 1.05, $CHCl_3$) for 68:32 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.84 (d, *J* = 7.5, 1H), 7.66–7.62 (m, 2H), 7.54 (t, *J* = 7.5, 1H), 7.41 (*J* = 8.5, 2H), 7.06 (d, *J* = 8.5, 2H), 5.91 (d, *J* = 6.0, 1H), 5.20 (d, *J* = 6.0, 1H), 2.29 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.1 (C), 169.0 (C), 150.9 (C), 146.1 (C), 133.9 (CH), 133.4 (C),

130.0 (CH), 129.7 (CH), 126.7 (C), 125.8 (CH), 123.7 (CH), 121.7 (CH), 82.4 (CH), 52.5 (CH), 21.1 (CH_3). **MS** (ESI) *m*/*z*: 383 (M + Na), 385 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{17}H_{14}O_4Br$, 361.0075; found, 361.0079. **IR** (NaCl): 3022, 2924, 2851, 1770, 1605, 1507, 1370, 1286, 1205, 1057, 735. The er was determined by **HPLC** (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:2, 0.6 mL/min, 220 nm, 40 °C, retention time = 34.9 min (3*R*,α*S*) and 39.6 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.

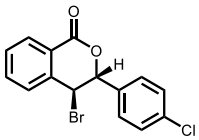


3e: Cololess solid of mp 113.8−115.2 °C. $[\alpha]_D^{24}$ +2.56 (*c* 0.812, $CHCl_3$) for 52:48 er; lit: $[\alpha]_D^{25}$ −58.6 (*c* 1.0, $CHCl_3$) for the other enantiomer with 80% ee.[3] **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.15 (d, *J* = 8.0, 1H), 7.62 (t, *J* = 7.0, 1H), 7.52–7.47 (m, 2H), 7.29 (d, *J* = 8.0, 2H), 7.07 (d, *J* = 8.0, 2H), 5.90 (d, *J* = 4.0, 1H), 5.31 (d, *J* = 4.0, 1H), 2.23 (s, 3H). ^{1}H NMR was in agreement with that reported.[3] The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:5, 0.6 mL/min, 254 nm, 40 °C, retention time = 22.2 min (3*R*,4*S*) and 29.6 min (3*S*,4*R*)).

(*S*)-3-[(*R*)-Bromo(4-chlorophenyl)methyl]isobenzofuran-1(3*H*)-one (2f) and (3*R*,4*S*)-4-Bromo-3-(4-chlorophenyl)-3,4-dihydroisochromen-1-one (3f): The typical procedure using **1f** (26.0 mg, 0.100 mmol) and the reaction for 120 h gave a 7:2 mixture of **2f** and **3f** (30.0 mg, 90%) as a colorless oil. The ratio of **2f** and **3f** was determined on the basis of the integral area of ^{1}H NMR signals at 5.15 and 5.50 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.

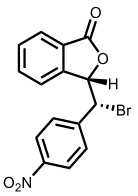


2f: Colorless solid of mp 137.2−138.5 °C. $[\alpha]_D^{24}$ –12.9 (*c* 0.700, $CHCl_3$) for 85:15 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.85 (d, *J* = 7.5, 1H), 7.67–7.64 (m, 2H), 7.54 (t, *J* = 7.5, 1H), 7.34 (d, *J* = 8.0, 2H), 7.28 (d, *J* = 8.0, 2H), 5.93 (d, *J* = 6.0, 1H), 5.15 (d, *J* = 6.0, 1H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.0 (C), 146.0 (C), 134.9 (C), 134.5 (C), 134.0 (CH), 130.1 (CH), 129.9 (CH), 128.8 (CH), 126.5 (C), 125.9 (CH), 123.6 (CH), 82.3 (CH), 52.1 (CH). **MS** (ESI) *m*/*z*: 337 (M + H), 339 (M + 2 + H), 341 (M + 4 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{15}H_{11}O_2ClBr$, 336.9631; found, 336.9643. **IR** (NaCl): 2913, 2852, 1758, 1592, 1491, 1289, 1210, 1052, 754. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 21.8 min (3*R*,α*S*) and 24.5 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



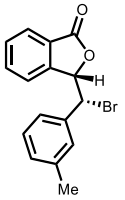
3f: Colorless solid of mp 130.5−131.5 °C. $[\alpha]_D^{24}$ +2.44 (*c* 0.531, $CHCl_3$) for 51:49 er; lit: $[\alpha]_D^{25}$ −51.0 (*c* 1.0, $CHCl_3$) for the other enantiomer with 95% ee.[3] **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.15 (dd, *J* = 8.0, 1.5, 1H), 7.62 (ddd, *J* = 8.0, 7.5 1.5, 1H), 7.51–7.48 (m, 2H), 7.32–7.30 (m, 2H), 7.26–7.23 (m, 2H), 5.84 (d, *J* = 5.0, 1H), 5.50 (d, *J* = 5.0, 1H). ^{1}H NMR was in agreement with that reported.[3] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:9, 0.6 mL/min,

220 nm, 40 °C, retention time = 22.0 min (3*R*,4*S*) and 25.5 min (3*S*,4*R*)).

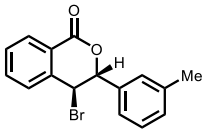


(*S*)-3-[(*R*)-Bromo(4-nitrophenyl)methyl]isobenzofuran-1(3*H*)-one (**2g)**: The typical procedure using **1g** (25.0 mg, 0.100 mmol) gave a crude product including a trace amount of **2g**. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.17 (d, *J* = 7.0, 2H), 7.84 (d, *J* = 7.0, 1H), 7.77–7.70 (m, 2H), 7.60–7.56 (m, 3H), 5.99 (d, *J* = 6.5, 1H), 5.19 (d, *J* = 6.5, 1H). ^{1}H NMR was in agreement with that reported.[9] The er was not determined. The absolute configuration was tentatively assigned by analogy.

(*S*)-3-[(*R*)-Bromo(3-methylphenyl)-methyl]isobenzofuran-1(3*H*)-one (**2h) and (3*R*,4*S*)-4-Bromo-3-(3-methylphenyl)-3,4-dihydroisochromen-1-one (3h)**: The typical procedure using **1h** (24.0 mg, 0.100 mmol) and the reaction for 120 h gave a 6:1 mixture of **2h** and **3h** (27.5 mg, 88%) as a colorless oil. The ratio of **2h** and **3h** was determined on the basis of the integral area of ^{1}H NMR signals at 5.15 and 5.85 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.



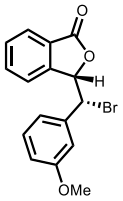
2h: Colorless solid of mp 118.9−119.5 °C. $[\alpha]_D^{24}$ –21.3 (*c* 0.372, $CHCl_3$) for 93:7 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.85 (d, *J* = 8.0, 1H), 7.68–7.62 (m, 2H), 7.54 (td, *J* =8.0, 1.0, 1H), 7.24–7.21 (m, 3H), 7.11 (m, 1H), 5.93 (d, *J* = 6.5, 1H), 5.15 (d, *J* = 6.5, 1H), 2.34 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.3 (C), 146.2 (C), 138.4 (C), 136.0 (C), 133.8 (CH), 129.9 (CH), 129.8 (CH), 129.1 (CH), 128.5 (CH), 126.7 (C), 125.7 (CH), 125.6 (CH), 123.9 (CH), 82.4 (CH), 53.5 (CH), 21.3 (CH_3). **MS** (ESI) *m*/*z*: 317 (M + H), 319 (M + 2 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{16}H_{14}O_2Br$, 317.0177; found, 317.0166. **IR** (NaCl): 2913, 2869, 1783, 1592, 1462, 1289, 1215, 1047, 985, 709. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 13.9 min (3*R*,α*S*) and 16.0 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



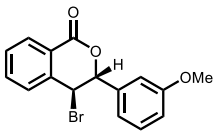
3h: Colorless oil. $[\alpha]_D^{24}$ +2.28 (*c* 0.803, $CHCl_3$) for 60:40 er; lit: $[\alpha]_D^{27}$ −71.2 (*c* 1.0, $CHCl_3$) for the other enantiomer with 90% ee.[3] **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.15 (d, *J* = 7.0, 1H), 7.59 (t, *J* = 7.5, 1H), 7.48 (t, *J* = 7.0, 2H), 7.19 (t, *J* = 7.5, 1H), 7.12−7.10 (m, 2H), 7.04 (d, *J* = 7.5, 1H), 5.88 (d, *J* = 4.5, 1H), 5.57 (d, *J* = 4.5, 1H), 2.31 (s, 3H). ^{1}H NMR was in agreement with that reported.[3] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:5, 0.6 mL/min, 220 nm, 40 °C, retention time = 22.2 min (3*S*,4*R*) and 24.1 min (3*R*,4*S*)).

9) Tsuchihashi, A.; Shirakawa, S. *Synlett*, **2019**, *30*, 1662.

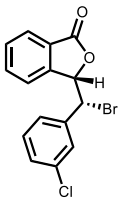
(*S*)-3-[(*R*)-Bromo(3-methoxyphenyl)methyl]isobenzofuran-1(3*H*)-one (2i) and (3*R*,4*S*)-4-Bromo-3-(3-methoxyphenyl)-3,4-dihydroisochromen-1-one (3i): The typical procedure using **1i** (26.0 mg, 0.100 mmol) gave a 7:2 mixture of **2i** and **3i** (23.5 mg, 71%) as a colorless oil. The ratio of **2i** and **3i** was determined on the basis of the integral area of ^{1}H NMR signals at 5.19 and 5.54 ppm in the crude mixture. The isomers were separated by preparative TLC (hexane/EtOAc 3:1) for characterization.



2i: Colorless solid of mp 83.6−84.7 °C. $[\alpha]_D^{24}$ –4.89 (*c* 0.564, $CHCl_3$) for 87:12 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.84 (d, *J* = 8.0, 1H), 7.66–7.51 (m, 3H), 7.22 (t, *J* = 8.0, 1H), 6.97–6.95 (m, 2H), 6.83 (m, 1H), 5.92 (d, *J* = 6.0, 1H), 5.19 (d, *J* = 6.0, 1H), 3.79 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.2 (C), 159.6 (C), 146.2 (C), 137.2 (C), 133.8 (CH), 129.9 (CH), 129.6 (CH), 126.7 (C), 125.7 (CH), 123.7 (CH), 120.7 (CH), 114.7 (CH), 114.2 (CH), 82.4 (CH), 55.3 (CH), 52.3 (CH_3). **MS** (ESI) *m*/*z*: 355 (M + Na), 357 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd for $C_{16}H_{13}O_3NaBr$, 354.9946; found, 354.9958. **IR** (NaCl): 3014, 2937, 2836, 1770, 1600, 1285, 1267, 1051, 756. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 22.2 min (3*R*,α*S*) and 24.2 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



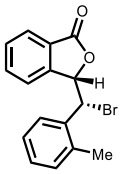
3i: Cololess solid of mp 92.2−93.5 °C. $[\alpha]_D^{28}$ +1.74 (*c* 0.241, $CHCl_3$) for 60:40 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.14 (d, *J* = 6.5, 1H), 7.60 (td, *J* = 7.5, 1.0, 1H), 7.50–7.45 (m, 2H), 7.23 (t, *J* = 7.5, 1H), 6.84–6.79 (m, 3H), 5.88 (d, *J* = 4.0, 1H), 5.54 (d, *J* = 4.0, 1H), 3.75 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 163.0 (C), 159.8 (C), 137.8 (C), 137.7 (C), 134.5 (CH), 130.4 (CH), 129.9 (CH), 129.8 (CH), 128.3 (CH), 124.1 (C), 118.6 (CH), 114.2 (CH), 112.3 (CH), 83.9 (CH), 55.2 (CH), 45.9 (CH_3). **MS** (ESI) *m*/*z*: 355 (M + Na), 357 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + K]^+$ calcd for $C_{16}H_{13}O_3KBr$, 370.9685; found, 370.9686. **IR** (NaCl): 3010, 2932, 2836, 1731, 1600, 1286, 1267, 1046, 755. The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:2, 0.6 mL/min, 254 nm, 40 °C, retention time = 17.6 min (3*R*,4*S*) and 19.4 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.



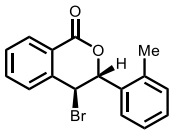
(*S*)-3-[(*R*)-Bromo(3-chlorophenyl)methyl]isobenzofuran-1(3*H*)-one (2j): The typical procedure using **1j** (26.0 mg, 0.100 mmol) and the reaction for 120 h gave **2j** (13.1 mg, 41%) as a colorless solid of mp 114.5−115.6 °C: $[\alpha]_D^{24}$ –8.21 (*c* 0.380, $CHCl_3$) for 78:22 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.86 (d, *J* = 7.5, 1H), 7.69–7.67 (m, 2H), 7.56 (m, 1H), 7.39 (d, *J* = 2.5,

1H), 7.33–7.27 (m, 3H), 5.91 (d, *J* = 7.0, 1H), 5.08 (d, *J* = 7.0, 1H). ^{1}H NMR was in agreement with that reported.[3)] The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:19, 0.6 mL/min, 220 nm, 40 °C, retention time = 26.6 min (3*R*,α*S*) and 29.6 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.

(*S*)-3-[(*R*)-Bromo(2-methylphenyl)methyl]isobenzofuran-1(3*H*)-one (2k) and (3*R*,4*S*)-4-Bromo-3-(2-methylphenyl)-3,4-dihydroisochromen-1-one (3k): The typical procedure using **1k** (24.0 mg, 0.100 mmol) and the reaction for 120 h gave a 3:1 mixture of **2k** and **3k** (24.2 mg, 77%) as a colorless oil. The ratio of **2k** and **3k** was determined on the basis of the integral area of ^{1}H NMR signals at 5.33 and 5.53 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.



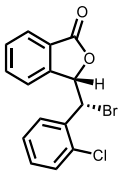
2k: Colorless solid of mp 148.5−149.4 °C. $[\alpha]_D^{24}$ +4.78 (*c* 0.750, $CHCl_3$) for 82:18 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.91 (d, *J* = 10.0, 1H), 7.83 (dd, *J* = 7.0, 1.0, 1H), 7.71–7.66 (m, 2H), 7.60 (t, *J* = 8.0, 1H), 7.31–7.22 (m, 2H), 7.16 (d, *J* = 8.0, 1H), 6.00 (d, *J* = 8.0, 1H), 5.33 (d, *J* = 8.0, 1H), 2.36 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.2 (C), 146.7 (C), 135.5 (C), 135.2 (C), 133.8 (CH), 130.8 (CH), 130.0 (CH), 128.9 (CH), 128.6 (CH), 126.7 (CH), 126.5 (C), 125.8 (CH), 124.6 (CH), 81.3 (CH), 49.9 (CH), 19.5 (CH_3). **MS** (ESI) *m*/*z*: 317 (M + H), 319 (M + 2 + H). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd for $C_{16}H_{14}O_2Br$, 317.0177; found, 317.0190. **IR** (NaCl): 3020, 2931, 2860, 1766, 1648, 1457, 1299, 1198, 1057, 968, 737. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 12.5 min (3*R*,α*S*) and 14.5 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



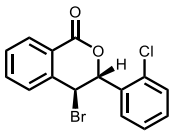
3k: Colorless oil. $[\alpha]_D^{24}$ +1.30 (*c* 0.784, $CHCl_3$) for 58:42 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.19 (dd, *J* = 8.0, 1.5, 1H), 7.64 (td, *J* = 8.0, 1.5, 1H), 7.53–7.50 (m, 2H), 7.25–7.21 (m, 2H), 7.12–7.05 (m, 2H), 6.09 (d, *J* = 5.0, 1H), 5.53 (d, *J* = 5.0, 1H), 2.48 (s, 3H). ^{1}H NMR was in agreement with that reported.[10)] The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:5, 0.6 mL/min, 254 nm, 40 °C, retention time = 12.9 min (3*R*,4*S*) and 13.6 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.

(*S*)-3-[(*R*)-Bromo(2-chlorophenyl)methyl]isobenzofuran-1(3*H*)-one (2l) and (3*RS*,4*SR*)-4-Bromo-3-(2-chlorophenyl)-3,4-dihydroisochromen-1-one (3l): The typical procedure using **1l** (26.0 mg, 0.100 mmol) at –40 °C gave a 3:1 mixture of **2l** and **3l** (24.0 mg, 72%) as a colorless oil. The ratio of **2l** and **3l** was determined on the basis of the integral area of ^{1}H NMR signals at 5.80 and 5.66 ppm in the crude mixture. The isomers were separated by preparative TLC (hexane/EtOAc 5:1) and further characterized.

10) Chen, T.; Yeung, Y. Y. *Org. Biomol. Chem.* **2016**, *14*, 4571.

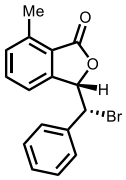


2l: Colorless solid of mp 110.2−111.8 °C. $[\alpha]_D^{20}$ –1.47 (*c* 0.134, $CHCl_3$) for 80:20 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.86 (d, *J* = 7.5, 1H), 7.75 (d, *J* = 7.5, 1H), 7.68−7.40 (m, 3H), 7.35−7.25 (m, 3H), 6.00 (d, *J* = 6.0, 1H), 5.80 (d, *J* = 6.0, 1H). ^{1}H NMR was in agreement with that reported.[3)] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:29, 0.6 mL/min, 220 nm, 40 °C, retention time = 21.0 min (3*R*,α*S*) and 27.1 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.

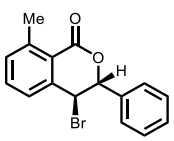


3l: Colorless solid of mp 129.7−131.1 °C in 50:50 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.20 (d, *J* = 8.0, 1H), 7.59 (t, *J* = 8.0, 1H), 7.51 (t, *J* = 8.0, 1H), 7.42–7.37 (m, 2H), 7.26 (t, *J* = 8.0, 1H), 7.16 (t, *J* = 8.0, 1H), 7.09 (d, *J* = 8.0, 1H), 6.30 (d, *J* = 3.5, 1H), 5.61 (d, *J* = 3.5, 1H). ^{1}H NMR was in agreement with that reported.[9)] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:29, 0.6 mL/min, 230 nm, 40 °C, retention time = 22.9 min and 25.5 min).

(*S*)-3-[(*R*)-Bromo(phenyl)methyl]-7-methylisobenzofuran-1(3*H*)-one (2m) and (3*R*,4*S*)-4-Bromo-3,4-dihydro-8-methyl-3-phenylisochromen-1-one (3m): The typical procedure using **1m** (24.0 mg, 0.100 mmol) gave a 1:2 mixture of **2m** and **3m** (19.3 mg, 61%) as a colorless oil. The ratio of **2m** and **3m** was determined on the basis of the integral area of ^{1}H NMR signals of the isomers at 5.20 and 5.52 ppm, respectively in the crude mixture. The isomers were separated by preparative TLC (hexane/EtOAc 5:1) and further characterized.



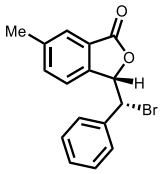
2m: Colorless oil. $[\alpha]_D^{24}$ –9.30 (*c* 0.300, $CHCl_3$) for 61:39 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.48 (t, *J* = 8.0, 1H), 7.41–7.35 (m, 3H), 7.33–7.27 (m, 4H), 5.86 (d, *J* = 6.0, 1H), 5.20 (d, *J* = 6.0, 1H), 2.62 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.3 (C), 146.7 (C), 139.8 (C), 136.0 (C), 133.4 (CH), 131.4 (CH), 128.9 (CH), 128.6 (CH), 128.5 (CH), 124.1 (C), 121.0 (CH), 81.7 (CH), 53.6 (CH), 17.3 (CH_3). **MS** (ESI) *m*/*z*: 339 (M + Na), 341 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd $C_{16}H_{13}O_2NaBr$ for, 338.9997; found, 338.9992. **IR** (NaCl): 3030, 2925, 1765, 1600, 1380, 1260, 1044. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 12.0 min (3*R*,α*S*) and 13.2 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



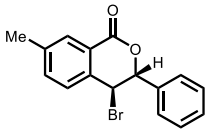
3m: Colorless solid of mp 93.6−94.5 °C. $[\alpha]_D^{28}$ –2.45 (*c* 0.660, $CHCl_3$) for 48:52 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.40 (*t*, *J* = 8.0, 1H), 7.30–7.20 (m, 7H), 5.87 (d, *J* = 4.0, 1H), 5.52 (d, *J* = 4.0, 1H), 2.72 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 162.3

(C), 143.3 (C), 138.5 (C), 136.4 (C), 133.4 (CH), 133.3 (CH), 128.8 (CH), 128.7 (CH), 126.2 (CH), 126.1 (CH), 122.7(C), 83.2 (CH), 47.2 (CH), 22.3 (CH_3). **MS** (ESI) *m*/*z*: 339 (M + Na), 341 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd $C_{16}H_{14}O_2Br$ for, 317.0177; found, 317.0182. **IR** (NaCl): 3020, 2924, 2851, 1730, 1216, 1118, 1050, 760. HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:5, 0.6 mL/min, 254 nm, 40 °C, retention time = 20.7 min (3*R*,4*S*) and 24.1 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.

(*S*)-3-[(*R*)-Bromo(phenyl)methyl]-6-methylisobenzofuran-1(3*H*)-one (2n) and (3*R*,4*S*)-4-Bromo-3,4-dihydro-7-methyl-3-phenylisochromen-1-one (3n): The typical procedure using **1n** (24.0 mg, 0.100 mmol) gave a 6:1 mixture of **2n** and **3n** (26.2 mg, 82%) as a colorless oil. The ratio of **2n** and **3n** was determined on the basis of the integral area of ^{1}H NMR signals at 5.19 and 5.55 ppm in the crude mixture. The isomers were separated by column chromatography (hexane/EtOAc 10:1) for characterization.



2n: Colorless solid of mp 154.1−154.8 °C. $[\alpha]_D^{24}$ –22.0 (*c* 1.11, $CHCl_3$) for 92:8 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.62 (s, 1H), 7.45–7.40 (m, 4H), 7.32–7.30 (m, 3H), 5.88 (d, *J* = 6.0, 1H), 5.19 (d, *J* = 6.0, 1H), 2.43 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.3 (C), 143.6 (C), 140.3 (C), 136.1 (C), 134.9 (CH), 129.0 (CH), 128.63 (CH), 128.60 (CH), 126.9 (C), 125.7 (CH), 123.4 (CH), 82.4 (CH), 53.7 (CH), 21.2 (CH_3). **MS** (ESI) *m*/*z*: 339 (M + Na), 341 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd $C_{16}H_{13}O_2NaBr$ for, 338.9997; found, 338.9992. **IR** (NaCl): 3030, 2920, 2850, 1760, 1490, 1294, 1150, 1062. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 18.3 min (3*R*,α*S*) and 20.3 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



3n: Colorless solid of mp 112.8−113.6 °C. $[\alpha]_D^{27}$ +1.51 (*c* 0.153, $CHCl_3$) for 63:37 er; lit: $[\alpha]_D^{27}$ +58.0 (*c* 1.0, $CHCl_3$) for the other enantiomer with 80% ee.[10] **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.96 (s, 1H), 7.39 (dd, *J* = 8.0, 1.0, 1H), 7.34–7.30 (m, 4H), 7.28–7.26 (m, 2H), 5.91 (d, *J* = 4.5, 1H), 5.55 (d, *J* = 4.5, 1H), 2.40 (s, 3H). ^{1}H NMR was in agreement with that reported.[11] The er was determined by HPLC (Daicel Chiralpak IC-3, *i*-PrOH/hexane 1:2, 0.6 mL/min, 230 nm, 40 °C, retention time = 15.5 min (3*R*,4*S*) and 16.6 min (3*S*,4*R*)).

(*S*)-3-[(*R*)-Bromo(phenyl)methyl]-6-chloroisobenzofuran-1(3*H*)-one (2o) and **(3*R*,4*S*)-4-Bromo-7-chloro-3,4-dihydro-3-phenylisochromen-1-one (3o)**: The typical procedure using **1o** (26.0 mg, 0.100 mmol) gave a 1:1 mixture of **2o** and **3o** (26.9 mg, 79%) as a colorless oil. The ratio of **2o** and **3o** was determined on the basis of the integral area of ^{1}H NMR signals at 5.21 and 5.52 ppm in the crude mixture. The isomers were separated by preparative TLC (hexane/EtOAc 5:1) for characterization.

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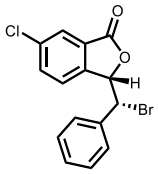
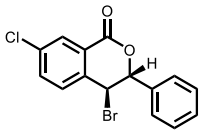
11) Nishiyori, R.; Tsuchihashi, A.; Mochizuki, A.; Kaneko, K.; Yamanaka, M.; Shirakawa, S. *Chem.–Eur. J*, 2018, **24**, 16747.

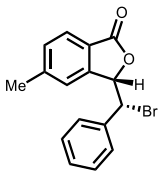


2o: Colorless solid of mp 119.2−120.3 °C. $[\alpha]_D^{24}$ –15.2 (*c* 0.840, $CHCl_3$) for 80:20 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.80 (d, *J* = 2.0, 1H), 7.60 (dd, *J* = 8.0, 2.0, 1H), 7.49 (d, *J* = 8.0, 1H), 7.41 (m, 2H), 7.35–7.33 (m, 3H), 5.89 (d, *J* = 6.0, 1H), 5.21 (d, *J* = 6.0, 1H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 167.6 (C), 144.3 (C), 136.4 (C), 135.6 (C), 134.0 (CH), 129.2 (CH), 128.8 (CH), 128.6 (C), 128.5 (CH), 125.6 (CH), 125.1 (CH), 82.2 (CH), 53.2 (CH). **MS** (ESI) *m*/*z*: 359 (M + Na), 361 (M + 2 + Na), 363 (M + 4 + Na). **HRMS** (ESI) *m*/*z*: $[M + K]^+$ calcd for, $C_{15}H_{10}O_2ClKBr$ for 374.9190; found, 374.9181. **IR** (NaCl): 3030, 2923, 1777, 1469, 1291, 1206, 1060, 757. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:11, 0.6 mL/min, 220 nm, 40 °C, retention time = 16.8 min (3*R*,α*S*) and 21.9 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



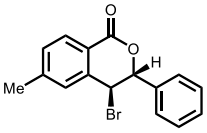
3o: Colorless solid of mp 149.5−150.2 °C. $[\alpha]_D^{29}$ +2.45 (*c* 1.22, $CHCl_3$) for 53:47 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.12 (d, *J* = 2.0, 1H), 7.55 (dd, *J* =8.0, 2.0, 1H), 7.41 (d, *J* = 8.0, 1H), 7.34–7.32 (m, 2H), 7.25 (m, 3H), 5.91 (d, *J* = 4.0, 1H), 5.52 (d, *J* = 4.0, 1H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 161.9 (C), 136.12 (C), 136.10 (C), 135.9 (C), 134.6 (CH), 130.2 (CH), 129.8 (CH), 129.1 (CH), 128.9 (CH), 126.3 (CH), 125.5 (C), 84.1 (CH), 45.0 (CH). **MS** (ESI) *m*/*z*: 359 (M + Na), 361 (M + 2 + Na), 363 (M + 4 + Na). **HRMS** (ESI) *m*/*z*: $[M + Na]^+$ calcd $C_{15}H_{10}O_2ClNar$ for, 358.9450; found, 358.9451. **IR** (NaCl): 3066, 2921, 2850, 1737, 1417, 1230, 1132, 1079, 755. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:5, 0.6 mL/min, 254 nm, 40 °C, retention time = 13.2 min (3*R*,4*S*) and 14.9 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.

(*S*)-3-[(*R*)-Bromo(phenyl)methyl]-5-methylisobenzofuran-1(3*H*)-one (2p) and (3*R*,4*S*)-4-Bromo-3,4-dihydro-6-methyl-3-phenylisochromen-1-one (3p): The typical procedure using **1p** (24.0 mg, 0.100 mmol) and NBP (27.1 mg, 0.100 mmol) gave a 1:1 mixture of **2p** and **3p** (27.1 mg, 85%) as a colorless oil. The ratio of **2p** and **3p** was determined on the basis of the integral area of ^{1}H NMR signals at 5.17 and 5.50 ppm in the crude mixture. The isomers were separated by preparative TLC (hexane/EtOAc 5:1) for characterization.



2p: Colorless solid of mp 151.1−152.8 °C. $[\alpha]_D^{24}$ +6.13 (*c* 0.402, $CHCl_3$) for 86:14 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 7.70 (d, *J* = 7.5, 1H), 7.42–7.40 (m, 3H), 7.34–7.30 (m, 4H), 5.88 (d, *J* = 6.0, 1H), 5.17 (d, *J* = 6.0, 1H), 2.48 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 169.2 (C), 146.8 (C), 145.1 (C), 136.1 (C), 131.0 (CH), 129.0 (CH), 128.6 (CH), 128.5 (CH), 125.5 (CH), 124.1 (C), 124.1 (CH), 82.2 (CH), 53.5 (CH), 22.1 (CH_3). **MS** (ESI) *m*/*z*: 339 (M + Na), 341 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd $C_{16}H_{14}O_2Br$ for, 317.0177; found, 317.0163. **IR** (NaCl): 3020, 2924, 1770, 1610, 1455, 1281,

1073, 770. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:29, 0.6 mL/min, 220 nm, 40 °C, retention time = 30.6 min (3*R*,α*S*) and 37.0 min (3*S*,α*R*)). The absolute configuration was tentatively assigned by analogy.



3p: Colorless solid of mp 109.2−110.8 °C. $[\alpha]_D^{29}$ +2.37 (*c* 0.400, $CHCl_3$) for 52:48 er. **^{1}H NMR** ($CDCl_3$, 400 MHz): 8.03 (d, *J* = 8.0, 1H), 7.32–7.24 (m, 7H), 5.90 (d, *J* = 4.5, 1H), 5.50 (d, *J* = 4.5, 1H), 2.40 (s, 3H). **^{13}C NMR** ($CDCl_3$, 100 MHz): 163.2 (C), 145.8 (C), 137.6 (C), 136.5 (C), 130.8 (CH), 130.5 (CH), 128.9 (CH), 128.8 (CH), 128.7 (CH), 126.4 (CH), 121.5 (C), 84.1 (CH), 46.3 (CH), 21.8 (CH_3). **MS** (ESI) *m*/*z*: 339 (M + Na), 341 (M + 2 + Na). **HRMS** (ESI) *m*/*z*: $[M + H]^+$ calcd $C_{16}H_{14}O_2Br$ for, 317.0177; found, 317.0182. **IR** (NaCl): 3030, 2923, 1729, 1613, 1375, 1239, 1077, 767. The er was determined by HPLC (Daicel Chiralpak AD-H, *i*-PrOH/hexane 1:5, 0.6 mL/min, 254 nm, 40 °C, retention time = 13.9 min (3*R*,4*S*) and 15.0 min (3*S*,4*R*)). The absolute configuration was tentatively assigned by analogy.

6. X-ray diffraction

Data collection and Structure solution details: Single crystal X-ray data for compound **2b** was collected on a Rigaku XtaLaB P200 diffractometer Cu-Kα radiation. Data collection, cell refinement, data reduction and analysis were carried out with the CrysAlisPro (Rigaku Oxford Diffraction). This structure was solved by intrinsic phasing methods with the SHELXT program and refines using SHELXL[12] with anisotropic displacement parameters for non-H atoms. CCDC 2189245 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from the Cambridge Crystallographic Data Centre via http://www.ccdc.cam.ac.uk/data_request/cif

X-ray crystallographic data for compound **2b** (CCDC 2189245).

Single crystals of **2b** were obtained by slow evaporation of a solution containing **2b** in the mixture of hexane and ethyl acetate at room temperature. A suitable crystal was selected and the crystal data and structure refinement results for compound **2b** are listed in the Table S1.

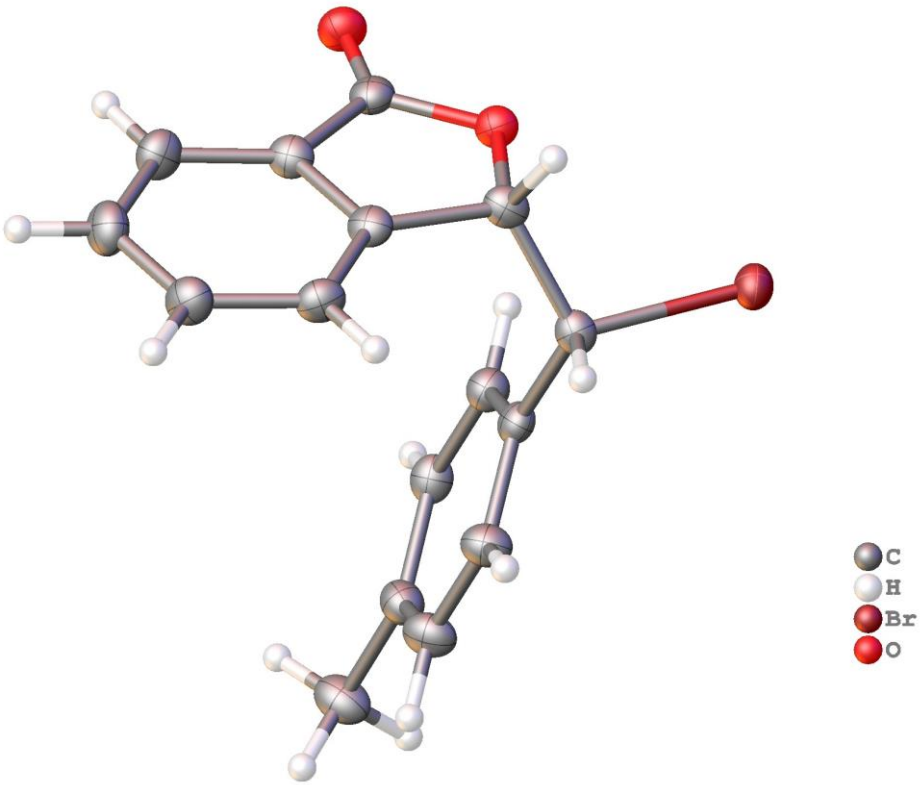


Figure S1. ORTEP view of the compound **2b** with thermal ellipsoids drawn at the 50% probability level

Table 1 Crystal data and structure refinement for 2b.

Identification code	220708KY_auto (1)
Empirical formula	$C_{16}H_{13}BrO_2$
Formula weight	317.17
Temperature/K	93

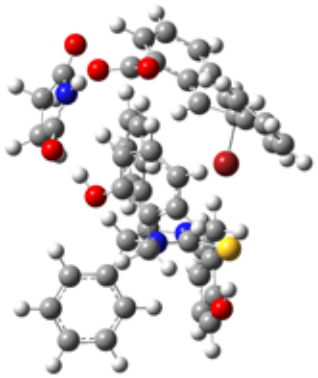
[12] Sheldrick, G. M. A. Short History of SHELX. *Acta Crystallogr., Sect. A: Found. Crystallogr.* **2008**, *64*, 112– 122.

Crystal system	tetragonal
Space group	$P4_3$
a/Å	8.67730(10)
b/Å	8.67730(10)
c/Å	17.8920(5)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1347.19(5)
Z	4
ρ_{calc}g/cm^3	1.564
μ/mm^{-1}	4.114
F(000)	640.0
Crystal size/mm^3	0.2 × 0.1 × 0.1
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	10.194 to 144.442
Index ranges	-5 ≤ h ≤ 9, -6 ≤ k ≤ 10, -21 ≤ l ≤ 20
Reflections collected	9588
Independent reflections	2584 [R_{int} = 0.0376, R_{sigma} = 0.0244]
Data/restraints/parameters	2584/1/173
Goodness-of-fit on F^2	1.101
Final R indexes [I>=2σ (I)]	R_1 = 0.0635, wR_2 = 0.1655
Final R indexes [all data]	R_1 = 0.0637, wR_2 = 0.1657
Largest diff. peak/hole / e Å^{-3}	1.06/-0.70
Flack parameter	-0.02(5)

7. DFT calculation

The initial transition state (TS) search was conducted using Gaussian 09W program at the B3LYP/6-31G(d) theoretical level. After conformational search, the geometry optimization of the conformers at the HF/3-21G theoretical level was performed with the coordinates of the two olefinic carbon atoms, the carboxylate oxygen atom, and the bromine atom fixed. Finally, TS search was performed at the ωB97X-D/6-31G(d) theoretical level to give the TS_{major} and TS_{minor}. The TS geometries were verified by vibrational frequency analysis. Single-point-energy calculations were performed at the ωB97X-D/6-311+G(d,p) theoretical level with solvation correction for dichloromethane using the Polarizable Continuum Model.

TS_{major}



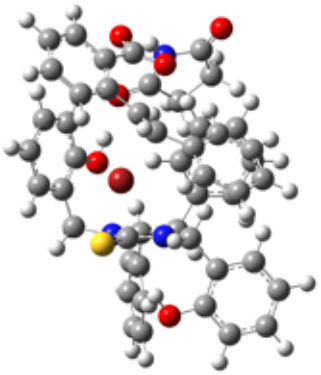
Energies (RwB97XD) =	–5439.18935341
Zero-point correction =	0.815083 (Hartree/Particle)
Thermal correction to Energy =	0.865968
Thermal correction to Enthalpy =	0.866912
Thermal correction to Gibbs Free Energy =	0.725214
Energies (RwB97XD:PCM) =	–5442.29554323
Sum of electronic and zero-point Energies =	–5441.480460
Sum of electronic and thermal Energies =	–5441.429575
Sum of electronic and thermal Enthalpies =	–5441.428631
Sum of electronic and thermal Free Energies =	–5441.570329

Atomic	Coordinates (Angstroms)		
Type	X	Y	Z
S	–1.402501	–3.407939	–0.459515
N	–1.731140	–1.291856	1.210896
C	–1.852625	–1.832289	–0.008870
C	4.233960	1.772265	0.622446
O	4.934869	0.770586	0.864945
O	3.862423	2.688040	1.391805
C	3.748448	1.902871	–0.827937
C	3.317443	0.763672	–1.562269
C	3.320473	–0.482600	–0.894525
H	3.366267	–0.488280	0.190547
C	3.333174	–1.795447	–1.522659
H	3.438542	–1.796150	–2.606791
Br	1.366832	–2.009133	–1.159430
C	–2.399554	0.014053	1.307241
H	–1.687825	0.739766	1.699429
C	–1.102970	–1.933932	2.362205
H	–1.343361	–2.999017	2.323078
H	–1.581814	–1.507597	3.248379
N	–2.426802	–0.934915	–0.840215
C	–2.740467	0.326180	–0.172859

H	–3.811275	0.528790	–0.281858
C	–2.771074	–1.142261	–2.233354
H	–2.266740	–0.376783	–2.834366
H	–2.356100	–2.111572	–2.524319
C	3.787666	3.135630	–1.468768
H	4.086284	4.013528	–0.909010
C	3.420517	3.246803	–2.805052
H	3.460638	4.220208	–3.284053
C	2.931136	0.897038	–2.917658
H	2.523804	0.041391	–3.447984
C	2.98S17	2.130535	–3.531062
H	2.665105	2.240787	–4.562665
C	4.143845	–2.852285	–0.831377
C	5.706219	–4.794713	0.406095
C	3.842935	–4.203368	–1.005349
C	5.232788	–2.47S48	–0.045446
C	6.0102S	–3.447765	0.572018
C	4.6214S	–5.171317	–0.385093
H	2.977108	–4.494283	–1.593955
H	5.461823	–1.418634	0.108553
H	6.849022	–3.147209	1.191755
H	4.378080	–6.221361	–0.513155
H	6.309708	–5.553145	0.895375
C	–3.606289	–0.047809	2.215254
C	–5.827644	–0.138643	3.899831
C	–3.672495	0.781445	3.332621
C	–4.652903	–0.935641	1.948956
C	–5.759430	–0.977983	2.788203
C	–4.783482	0.738841	4.172494
H	–2.845188	1.452875	3.548908
H	–4.601964	–1.603318	1.090580
H	–6.568456	–1.670338	2.575866
H	–4.827783	1.387194	5.042556
H	–6.692726	–0.174476	4.555528
C	–1.95S20	1.468072	–0.774156
C	–0.486843	3.525924	–1.968947
C	–0.555456	1.465277	–0.711157
C	–2.605002	2.509066	–1.430947
C	–1.876492	3.536829	–2.029730
C	0.S8041	2.491893	–1.301478
H	–0.033792	0.648074	–0.217011
H	–3.691096	2.507204	–1.486304
H	–2.396205	4.339193	–2.545400
H	1.247737	2.498439	–1.230954
H	0.094658	4.319741	–2.429447
C	–4.262655	–1.057319	–2.449152
C	–7.031146	–0.783340	–2.752881
C	–4.805769	–0.006792	–3.190682
C	–5.135427	–1.983048	–1.854282
C	–6.515628	–1.835534	–2.009299
C	–6.177717	0.139532	–3.353547
H	–4.125774	0.713913	–3.640146
H	–7.S5084	–2.565809	–1.537828
H	–6.575934	0.963601	–3.936547
H	–8.106764	–0.684193	–2.864485
O	–4.728381	–3.027295	–1.091744
C	0.396279	–1.744067	2.4S424
C	3.S4217	–1.357941	2.492942
C	0.932954	–0.475880	2.689985
C	1.268974	–2.806880	2.203196
C	2.649392	–2.627689	2.247618

C	2.312845	–0.275199	2.703935
H	0.852500	–3.785069	1.977587
H	3.3S857	–3.465399	2.069740
H	2.721983	0.718282	2.873346
H	4.234946	–1.180853	2.497215
O	0.050176	0.5S726	2.946502
H	0.478495	1.3932S	2.979054
C	1.444442	5.283174	0.S9555
C	0.064199	5.881247	0.413727
C	–0.61S03	4.900594	1.370653
C	0.510547	3.982706	1.825202
N	1.628488	4.252333	1.076588
H	–0.454629	6.010303	–0.537398
H	0.201070	6.873283	0.856253
H	–1.087909	5.360739	2.238750
H	–1.359673	4.279499	0.865244
O	0.423218	3.140461	2.698335
O	2.247830	5.644670	–0.661996
H	–3.764861	–3.170073	–1.117156
H	2.509636	3.692210	1.159337

TS_{minor}



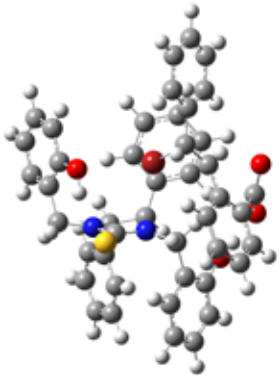
Energies (RwB97XD) =	–5439.19244055
Zero-point correction =	0.815672 (Hartree/Particle)
Thermal correction to Energy =	0.866499
Thermal correction to Enthalpy =	0.867444
Thermal correction to Gibbs Free Energy =	0.727434
Energies (RwB97XD:PCM) =	–5442.29615823
Sum of electronic and zero-point Energies =	–5441.480486
Sum of electronic and thermal Energies =	–5441.429659
Sum of electronic and thermal Enthalpies =	–5441.428714
Sum of electronic and thermal Free Energies =	–5441.568724

Atomic	Coordinates (Angstroms)		
Type	X	Y	Z
S	1.543677	–2.127623	–2.397966
N	1.713287	0.562268	–2.089842
C	1.825043	–0.640126	–1.544300
C	2.122240	1.616256	–1.142781
H	1.290635	2.316117	–1.052012
C	1.049615	0.871938	–3.364501
H	1.524501	0.284636	–4.153897
H	1.263382	1.927062	–3.553578
N	2.192223	–0.567297	–0.264138
C	2.321103	0.827260	0.181381
H	3.340495	0.973713	0.551749
C	2.403196	–1.660652	0.677347

H	1.657604	–1.571504	1.473203
H	2.194531	–2.598730	0.157218
C	3.360982	2.327911	–1.633246
C	5.636466	3.659479	–2.547084
C	3.312729	3.692239	–1.909127
C	4.555498	1.626957	–1.825341
C	5.687625	2.291742	–2.278911
C	4.448764	4.358629	–2.363249
H	2.379839	4.232899	–1.770296
H	4.602878	0.557404	–1.626599
H	6.612861	1.742881	–2.425060
H	4.402067	5.422626	–2.574263
H	6.523004	4.176155	–2.902088
C	1.339852	1.149071	1.284893
C	–0.444728	1.691152	3.358865
C	–0.031110	0.948376	1.102205
C	1.808867	1.625068	2.508059
C	0.918364	1.899168	3.544659
C	–0.922268	1.220082	2.135039
H	–0.400141	0.542152	0.162056
H	2.876565	1.770056	2.654382
H	1.294005	2.265685	4.495724
H	–1.987221	1.031166	2.004011
H	–1.149615	1.885893	4.162864
C	3.795206	–1.606830	1.250260
C	6.372847	–1.360073	2.300411
C	3.991959	–1.315563	2.600383
C	4.916666	–1.779119	0.425895
C	6.200878	–1.649918	0.953350
C	5.268959	–1.195415	3.134631
H	3.116794	–1.171251	3.228612
H	7.048539	–1.787164	0.290146
H	5.403078	–0.971444	4.187792
H	7.377315	–1.263723	2.701511
O	4.827762	–2.039132	–0.908078
C	–0.434322	0.602588	–3.318123
C	–3.156947	0.038711	–3.123665
C	–1.269752	1.407550	–2.528041
C	–0.992163	–0.462217	–4.023309
C	–2.348610	–0.749213	–3.936295
C	–2.630300	1.111577	–2.413607
H	–0.343816	–1.080321	–4.638307
H	–2.769533	–1.586416	–4.483403
H	–3.265318	1.713694	–1.769208
H	–4.214391	–0.183884	–3.029733
O	–0.697039	2.460923	–1.895244
C	–3.289327	3.634757	2.944400
C	–2.147820	4.651727	2.953157
C	–1.614444	4.641562	1.521588
C	–2.630987	3.815931	0.750370
N	–3.542284	3.298871	1.617167
H	–1.409997	4.367093	3.704970
H	–2.560308	5.623182	3.242885
H	–1.517544	5.628345	1.062651
H	–0.645629	4.137104	1.440824
O	–2.628163	3.633905	–0.460080
O	–3.875398	3.204183	3.905948
H	3.935013	–2.320066	–1.157432
H	–4.225313	2.560990	1.300339
C	–4.454174	0.243561	0.716137
O	–3.716673	0.000713	1.700643

O	–5.000043	1.334802	0.423705
C	–4.709767	–0.899405	–0.271407
C	–3.792102	–1.952444	–0.463984
C	–2.577914	–1.982813	0.342074
H	–2.256787	–1.031116	0.741689
C	–1.913527	–3.118732	0.781170
H	–2.277771	–4.097360	0.472434
Br	–0.512143	–2.456552	–1.021574
C	–5.889565	–0.894124	–1.013887
H	–6.575427	–0.067347	–0.863243
C	–6.168077	–1.905935	–1.924936
H	–7.098375	–1.889473	–2.485319
C	–4.064339	–2.949979	–1.410785
H	–3.318270	–3.713964	–1.613441
C	–5.244557	–2.930845	–2.136115
H	–5.442411	–3.704881	–2.871205
C	–0.944508	–3.082772	1.894664
C	0.953971	–2.973653	3.940258
C	0.037068	–4.075819	2.003191
C	–0.986831	–2.052863	2.839284
C	–0.031949	–1.995407	3.850499
C	0.982483	–4.020761	3.017772
H	0.073252	–4.872936	1.264894
H	–1.778892	–1.311170	2.796469
H	–0.066694	–1.182713	4.569116
H	1.747618	–4.787677	3.087699
H	1.697004	–2.929917	4.731067
H	–1.379260	2.973767	–1.405634

TS_{major} without a succinimide residue



Energies (RwB97XD) =	–5078.59701649
Zero-point correction =	0.719993 (Hartree/Particle)
Thermal correction to Energy =	0.763483
Thermal correction to Enthalpy =	0.764427
Thermal correction to Gibbs Free Energy =	0.640317
Energies (RwB97XD:PCM) =	–5081.59975719
Sum of electronic and zero-point Energies =	–5080.879764
Sum of electronic and thermal Energies =	–5080.836274
Sum of electronic and thermal Enthalpies =	–5080.835330
Sum of electronic and thermal Free Energies =	–5080.959440

Atomic	Coordinates (Angstroms)		
Type	X	Y	Z
S	1.021586	0.344587	–2.923496
N	2.082968	1.727544	–0.847879
C	1.483295	0.609214	–1.312760
C	–1.539393	–3.337539	1.747335
O	–2.616037	–2.970906	2.249088

O	–0.426719	–3.500258	2.303482
C	–1.517095	–3.607155	0.226597
C	–2.190948	–2.781021	–0.710246
C	–2.934575	–1.679308	–0.193304
H	–2.997189	–1.656485	0.894864
C	–3.718468	–0.706390	–0.940370
H	–3.825661	–0.879718	–2.008457
Br	–2.021076	0.365714	–0.702513
C	2.489011	1.591475	0.554667
H	2.218682	2.500290	1.098934
C	2.261439	2.970212	–1.571069
H	2.147120	2.748092	–2.635794
H	3.291690	3.309126	–1.417258
N	1.289535	–0.230195	–0.280167
C	1.622489	0.399560	1.013481
H	2.207103	–0.305785	1.609452
C	0.946836	–1.637846	–0.383231
H	0.296847	–1.871940	0.457985
H	0.378900	–1.767277	–1.306742
C	–0.720426	–4.642693	–0.257145
H	–0.169738	–5.244682	0.457080
C	–0.597809	–4.867223	–1.620875
H	0.035451	–5.674759	–1.975751
C	–2.035184	–3.004598	–2.096786
H	–2.493312	–2.332976	–2.816064
C	–1.250924	–4.043858	–2.548197
H	–1.120386	–4.208561	–3.612100
C	–4.898574	–0.044506	–0.324494
C	–7.156903	1.214463	0.718814
C	–5.833485	0.546976	–1.176834
C	–5.099704	–0.001980	1.059142
C	–6.226792	0.625560	1.573047
C	–6.959672	1.174567	–0.657841
H	–5.676234	0.520520	–2.252120
H	–4.389276	–0.454258	1.743645
H	–6.380724	0.651464	2.647041
H	–7.681547	1.629128	–1.328703
H	–8.036832	1.700975	1.128020
C	3.981145	1.364923	0.688253
C	6.726003	0.932443	0.989124
C	4.759212	2.256034	1.424080
C	4.590899	0.256289	0.092851
C	5.953622	0.039615	0.247747
C	6.127960	2.042999	1.574787
H	4.290663	3.119781	1.891015
H	4.002720	–0.449218	–0.487133
H	6.407390	–0.835181	–0.207754
H	6.723717	2.742213	2.153980
H	7.791212	0.760499	1.111674
C	0.338264	0.756564	1.747219
C	–2.166791	1.237018	2.906198
C	–0.286065	1.999269	1.600974
C	–0.295197	–0.230343	2.505072
C	–1.548515	–0.000840	3.067436
C	–1.525690	2.240148	2.184850
H	0.175389	2.794616	1.026026
H	0.177854	–1.195244	2.655480
H	–2.032481	–0.807604	3.608940
H	–1.993520	3.211448	2.053056
H	–3.141452	1.423003	3.349095
C	2.182587	–2.507409	–0.389236

C	4.645230	–3.832852	–0.424455
C	2.869905	–2.710425	–1.589232
C	2.724499	–3.017202	0.802002
C	3.961651	–3.667275	0.772712
C	4.095483	–3.365527	–1.617214
H	2.442223	–2.311661	–2.505825
H	4.364710	–4.036349	1.710078
H	4.617675	–3.504958	–2.558702
H	5.605647	–4.340877	–0.427980
O	2.132964	–2.844907	2.010747
H	1.180677	–3.120939	2.004945
C	1.294133	4.029873	–1.087665
C	–0.465333	5.922497	0.000247
C	–0.093340	3.907095	–1.284801
C	1.764975	5.112718	–0.342030
C	0.905585	6.060056	0.201881
C	–0.960033	4.857883	–0.740093
H	2.837385	5.203018	–0.182408
H	1.299941	6.890197	0.778519
H	–2.024594	4.729520	–0.906463
H	–1.155617	6.649193	0.418498
O	–0.684715	2.886456	–1.949602
H	–0.053458	2.288713	–2.402401