[4+2]-Cycloaddition Reactions Catalyzed by a Chiral Oxazaborolidinium Cation. Reaction Rates, Diastereo-, Regio- and Enantioselectivity Depend on Whether Both Bonds Are Formed Simultaneously

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SUPPORTING INFORMATION: PART A

General: Infrared (FT-IR) spectra were recorded on a Bruker Tensor 27, ν_{max} in cm^{-1}. Bands are characterized as broad (br), strong (s), medium (m), and weak (w). ^{1}H-NMR spectra were recorded on a Varian Unity INOVA 600 (600 MHz) or Varian Unity INOVA 500 (500 MHz) or a Varian Unity INOVA 400 (400 MHz) spectrometer. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard ($CDCl_3$: δ 7.26 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz) and integration. ^{13}C-NMR spectra were recorded on a Varian Unity INOVA 500 (125 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard ($CDCl_3$: δ 77.00 ppm). ^{11}B-NMR spectra were recorded on a Varian Unity INOVA 300 (96 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm from BF_3-Et_2O (δ 0.00 ppm). High-resolution mass spectrometry was performed on either an Agilent 6210 Time-of-Flight LC/MS. Enantiomer ratios were determined by GC analysis using chiral capillary column [J&W Scientific Cyclosil-B column (30 m × 0.25 mm)] or HPLC analysis using chiral columns [Chiralcel OJ and Chiralpak AD columns (25 cm × 0.46 cm)] in comparison with authentic racemic materials.[1] GC-analyses were performed on Hewlett-Packard 6850 Series GC System equipped with flame-ionization detector. Optical rotations were measured on a Perkin Elmer 241 Polarimeter. Melting points were measured using a Büchi 535 Melting point apparatus. All melting points were measured in open glass capillary and values are uncorrected.

Unless otherwise noted, all reactions have been carried out with distilled and dried solvents under an atmosphere of dry N_2 in oven- (140 ^{o}C) and flame-dried glassware with standard vacuum-line techniques. Toluene was purified under a positive pressure of dry argon by passage through activated alumina columns. Dichloromethane was purified by distillation from calcium hydride

(1) Racemic Diels-Alder adducts were prepared either by using $EtAlCl_2$ as catalyst (0.2 – 1.0 equiv) or without any catalyst at rt

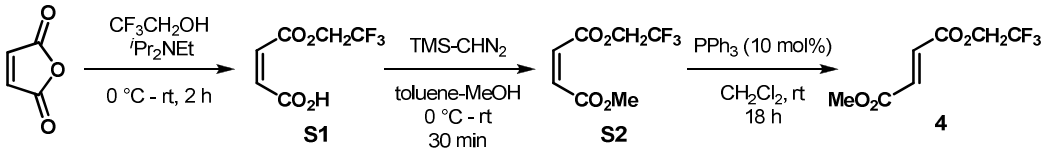
immediately prior to use. All work-up and purification procedures were carried out with reagent grade solvents (purchased from VWR) in air. Thin-layer chromatography (TLC) was performed using E. Merck silica gel 60 F_{254} precoated plates (0.25 mm). Flash chromatography was performed using Baker silica gel (40 μm particle size).

- **Reagents and catalysts:**

Borontribromide was purchased from Aldrich and used as received.
Cyclopentadiene was isolated by thermal cracking of dicyclopentadiene and stored over 4 Å molecular sieves at -78 ºC.
***N*,*N*′-Dicyclohexylcarbodiimide (DCC)** was from Aldrich and used as received.
Diisopropylethylamine was distilled from CaH_2 under a nitrogen atmosphere prior to use.
Diisopropyl-L-tartrate was purchased from Aldrich and used as received.
4-(Dimethylamino)pyridine (DMAP) was purchased from Fluka and used as received.
(*S*)-(-)-α,α-Diphenyl-2-pyrrolidinemethanol was purchased from Aldrich and used as received.
Ethyl chloroformate was purchased from Aldrich and used as received.
Iodine was purchased from Aldrich and used as received.
Lead tetraacetate was purchased from Aldrich and used as received.
LHMDS was purchased from Aldrich as a 1.0 M solution in THF and used as received.
Maleamic acid was purchased from Aldrich and used as received.
Maleic anhydride was purchased from Lancaster and used as received.
Methanesulfonyl chloride was purchased from Fluka and used as received.
Methylcyclopentadiene was isolated by thermal cracking of methyl-dicyclopentadiene and stored over 4 Å molecular sieves at -78 ºC. This is ~1:1 mixture of 1- and 2-methylcyclopentadiene.
***N*,*N*,*N*′,*N*′-Tetramethyl-L-tartaramide** was purchased from Aldrich and used as received.
Triethylamine was purchased from Aldrich and distilled over CaH_2 prior to use.
Triflimide was obtained from Aldrich and used as received.
2,2,2-Trifluoroethanol was purchased from Aldrich and used as received.
(Trimethylsilyl)diazomethane was purchased from Aldrich as a 2.0M solution in diethylether and used as received.
Triphenylphosphine was purchased from Aldrich and used as received.

- **Synthesis of dienophiles:**

Methyl 2,2,2-trifluoroethyl fumarate (**4**):

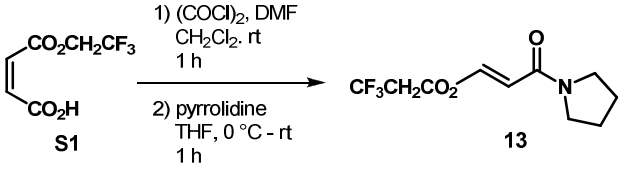


Diisopropylethylamine (9.77 mL; 56.1 mmol) was added over a few min to an ice-cold slurry of maleic anhydride (5.0 g; 51 mmol) in trifluoroethanol (3.67 mL; 51 mmol) in a 50 mL round-bottom flask under positive pressure of nitrogen. After a few min the cooling bath was removed and the resulting thick solution was stirred at room temperature for 2 h. The reaction mixture was then acidified with 6N HCl to pH ~1 and extracted with EtOAc-DCM (4:1) mixture (25 mL × 5). Combined organic layers were dried over anh. Na_2SO_4 and concentrated in vacuo to obtain an off-white solid (7.60 g, 38.4 mmol; 75% yield) which was used for the next step without further purification.

S1 (3.8 g; 19.2 mmol) was placed in an oven-dried 50 mL round-bottom flask under nitrogen together with 20 mL toluene-MeOH (4:1) and cooled to 0 °C with an ice-bath. A solution of (trimethylsilyl)diazomethane (10.0 mL of 2.0M in Et_2O; 20.0 mmol) was the added over 15 min. After stirring for further 15 min at 0 °C, the reaction mixture was allowed to warm to ambient temperature and concentrated to obtain an yellow oil. Silica gel column chromatographic purification (5:1 hexanes/EtOAc) afforded **S2** as a colorless oil (3.5 g, 16.5 mmol; 86% yield). **FT-IR (thin film):** 3014 (w), 1734 (s), 1644 (m), 1439 (m), 1415 (m), 1390 (m), 1282 (s), 1243 (w), 1150 (s), 1047 (m), 978 (m), 888 (w), 844 (w), 823 (m), 658 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.36 (d, *J* = 12.3 Hz; 1H), 6.27 (d, *J* = 12.3 Hz; 1H), 4.54 (q, *J* = 8.5 Hz; 2H), 3.78 (s; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 165.1, 163.4, 131.7, 127.6, 122.7 (q, *J* = 275 Hz), 60.8 (q, *J* = 36.8 Hz), 52.3.

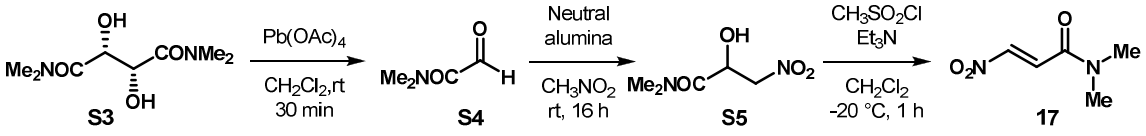
Triphenylphosphine (247 mg; 0.943 mmol) was added to a solution of **S2** (2.00 g; 9.43 mmol) in 12 mL dichloromethane at rt The resulting mixture was stirred at rt for 18 h and concentrated in vacuo to obtain a colorless oil. Purification by silica gel column chromatography (10:1 hexanes/EtOAc) afforded **4** as a colorless oil (1.71 g, 8.06 mmol; 85% yield). **FT-IR (thin film):** 2961 (w), 1731 (s), 1649 (w), 1439 (m), 1414 (w), 1311 (s), 1274 (s), 1149 (s), 1071 (w), 1051 (m), 978 (s), 843 (w), 772 (m), 679 (w), 638 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.95 (d, *J* = 16.0 Hz; 1H), 6.89 (d, *J* = 16.0 Hz; 1H), 4.57 (q, *J* = 8.5 Hz; 2H), 3.82 (s; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 164.8, 163.2, 135.4, 131.5, 122.7 (q, *J* = 275 Hz), 60.8 (q, *J* = 36.8 Hz), 52.4.

(E)-2,2,2-Trifluoroethyl 4-oxo-4-(pyrrolidin-1-yl)but-2-enoate (**13**):



S1 (1.45 g; 7.32 mmol) was placed in a 25 mL round-bottom flask together with 10 mL dichloromethane and oxalyl chloride (1.60 mL; 18.30 mmol) was added to the solution followed by a drop of DMF. The resulting solution was stirred at rt for 1 h and volatiles were removed under reduced pressure. The residue was taken in tetrahydrofuran (8 mL) and cooled to 0 °C under nitrogen. Pyrrolidine (1.21 mL; 14.64 mmol) was then added via syringe over 30 min. After the addition was complete, the resulting mixture was allowed to warm to ambient temperature and stirred at that temperature for 30 min. The reaction mixture was diluted with water (30 mL) and extracted with EtOAc (25 mL × 3). Combined organic layers were washed with sat. aqueous $NaHCO_3$ solution, dried over anh. Na_2SO_4 and concentrated to obtain an yellow oil. Crude ^{1}H-NMR revealed this as a mixture of (*E*)- and (*Z*)-isomers. Silica gel column chromatography (1:1 CH_2Cl_2/EtOAc) afforded **13** as a white crystalline solid (772 mg, 3.11 mmol; 42% yield). **Melting point:** 70-72 °C; **FT-IR (thin film):** 2983 (w), 2886 (w), 1733 (s), 1657 (s), 1614 (s), 1447 (s), 1309 (s), 1266 (s), 1157 (s), 1052 (w), 985 (s), 847 (w), 763 (m), 736 (m), 668 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 7.33 (d, *J* = 15.3 Hz; 1H), 6.91 (d, *J* = 15.3 Hz; 1H), 4.58 (q, *J* = 8.5 Hz; 2H), 3.55-3.62 (m; 4H), 1.99-2.04 (m; 2H), 1.89-1.94 (m; 2H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 164.1, 161.8, 136.7, 128.5, 122.7 (q, *J* = 275 Hz), 60.6 (q, *J* = 36.8 Hz), 46.8, 46.2, 26.0, 24.2.

(E)-N,N-dimethyl-3-nitroacrylamide (**17**):



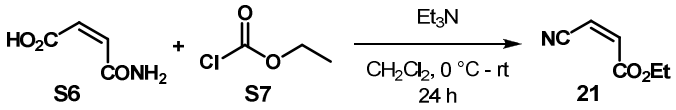
N,N,N′,N′-Tetramethyl-L-tartaramide **S3** (1.00 g; 4.90 mmol) was taken in a 50 mL round bottom flask in 20 mL dichloromethane and $Pb(OAc)_4$ (2.61 g; 5.88 mmol) was added in one portion at rt and the resulting suspension was stirred at rt for 30 min. The reaction mixture was filtered through a Celite® pad and thoroughly washed with dichloromethane (50 mL). The filtrate was concentrated in vacuo to obtain **S4** as a thick colorless oil which was used immediately without further purification.

To a solution of this oil in 12 mL nitromethane at rt, neutral alumina (3.0 g) was added and the resulting suspension was stirred at rt for 16 h. The solid was filtered through a Celite® pad and washed with EtOAc. The filtrate was concentrated in vacuo to obtain an orange oil. Purification by

silica gel column chromatography (CH_2Cl_2 to 20:1 CH_2Cl_2/MeOH) afforded **S5** as a pale yellow oil (1.06 g, 6.54 mmol; 67% yield from **S3**). **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 5.04-5.07 (m; 1H), 4.56-4.60 (m; 1H), 4.42-4.46 (m; 1H), 3.09 (s; 3H), 2.97 (s; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 168.9, 77.8, 66.1, 36.5, 35.9.

S5 (975 mg; 6.01 mmol) was taken in a 50 mL oven-dried round-bottom flask together with 12 mL abs. CH_2Cl_2 and the resulting solution was cooled to -20 °C under nitrogen. Methanesulfonyl chloride (1.40 mL; 18.03 mmol) was then added via syringe over 15 min followed by slow addition of Et_3N (2.51 mL; 18.03 mmol) over 10 min. The resulting yellow slurry was stirred at -20 °C for 1 h. Ice-cold water (50 mL) was the added to the reaction mixture and stirred vigorously at rt for 15 min. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (20 mL × 3). Combined organic layers was washed with water (20 mL × 3) and brine (20 mL), dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a yellow oil. Purification by silica gel column chromatography (1:1 hexanes/EtOAc) afforded **17** as a pale yellow crystalline solid (725 mg, 5.03 mmol; 84% yield). **Melting point:** 39-40 °C; **FT-IR (thin film):** 3112 (w), 2935 (w), 1661 (s), 1620 (s), 1526 (s), 1400 (s), 1351 (s), 1286 (w), 1257 (m), 1222 (w), 1140 (s), 1060 (m), 941 (s), 867 (m), 753 (s), 712 (s), 620 (s); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 7.63 (d, *J* = 13.0 Hz; 1H), 7.58 (d, *J* = 13.0 Hz; 1H), 3.13 (s; 3H), 3.03 (s; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 161.9, 147.6, 128.2, 37.9, 36.0.

(Z)-Ethyl 3-cyanoacrylate (**21**):

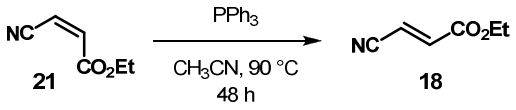


(*Z*)-Ethyl 3-cyanoacrylate **21** was prepared according to the literature procedure.[2] In a 50 mL oven-dried round bottom flask equipped with a magnetic stirring bar and a pressure equalized dropping funnel, maleamic acid **S6** (2.30 g; 20.0 mmol) was taken together with abs. dichloromethane (25 mL) under nitrogen. The resulting milky solution was cooled to 0 °C and triethylamine (5.71 mL; 41.0 mmol) was added followed by dropwise addition of ethyl chloroformate **S7** (4.15 mL; 43.4 mmol) over 30 min. After the addition was complete, the reaction mixture was allowed to warm to rt and stirred at rt for 24 h. A 10% aqueous NaOH solution was added to the reaction mixture and the organic layer was separated. The aqueous layer was extracted with dichloromethane (20 mL × 3) and the combined organic layers was dried over anh. $MgSO_4$. Concentration in vacuo afforded a pale brown oil. Purified by silica gel column chromatography (10:1 to 3:1 hexanes/Et_2O) to obtain a pale yellow oil. Further purification was achieved by bulb-to-bulb distillation (~110 °C, 10 mmHg) to obtain a colorless oil (1.50 g, 12.00 mmol; 60% yield). **FT-IR (thin film):** 3064 (w), 2987 (w), 1725 (s), 1628 (m), 1467 (w), 1385 (s), 1291 (m), 1226 (s), 1187 (s), 1096 (w), 1024 (s), 868 (w),

(2) Sauers, C. K.; Cotter, R. J. *J. Org. Chem.* **1961**, *26*, 6-10.

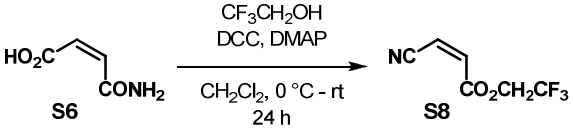
822 (s); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.55 (d, *J* = 11.5 Hz; 1H), 5.94 (d, *J* = 11.5 Hz; 1H), 4.28 (q, *J* = 7.0 Hz; 2H), 1.32 (t, *J* = 7.0 Hz; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 162.3, 138.3, 114.2, 110.5, 61.8, 13.8.

(E)-Ethyl 3-cyanoacrylate (**18**):



(*Z*)-Ethyl 3-cyanoacrylate **21** (250 mg; 2.00 mmol) was taken in a 10 mL round botton flask together with 2 mL CH_3CN and PPh_3 (105 mg; 0.4 mmol) was added. The resulting solution was refluxed at 90 °C for 48 h. The reaction mixture was then allowed to cool to ambient temperature and concentrated in vacuo to obtain a pale brown oil. Purification by silica gel column chromatography (10:1 to 4:1 hexanes/EtOAc, gradient) afforded **18** as a colorless oil (130 mg, 1.04 mmol; 52% yield, 65% based on recovered **21**). **FT-IR (thin film):** 3067 (w), 2984 (w), 1722 (s), 1635 (w), 1372 (w), 1388 (s), 1293 (m), 1226 (s), 1195 (s), 1025 (s), 875 (w), 822 (s), 750 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.70 (d, *J* = 16.8 Hz; 1H), 6.48 (d, *J* = 16.8 Hz; 1H), 4.28 (q, *J* = 7.0 Hz; 2H), 1.32 (t, *J* = 7.0 Hz; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 163.2, 139.9, 115.4, 112.8, 62.1, 14.0.

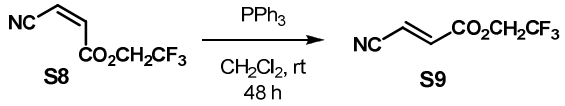
(Z)-2,2,2-Trifluoroethyl 3-cyanoacrylate (**S8**):



In a 50 mL oven-dried round-bottom flask, maleamic acid **S6** (2.00 g; 17.38 mmol) and DMAP (425 mg; 3.48 mmol) was taken in 20 mL abs. CH_2Cl_2 and CF_3CH_2OH (3.75 mL; 3.00 mmol) was added. The resulting milky solution was cooled to 0 °C under nitrogen and a solution of DCC (5.38 g; 26.07 mmol) in 10 mL abs. CH_2Cl_2 was added. After stirring for 10 min at 0 °C, the cooling bath was removed and the reaction mixture was stirred at rt for 24 h. The reaction mixture was filtered through a short plug of silica gel and Celite®, and washed with Et_2O (50 mL). The filtrate was concentrated in vacuo to obtain an orange oil. Purification by silica gel column chromatography (5:1 to 2:1 hexanes/EtOAc, gradient) afforded a thick colorless oil which was further purified by Kugelrohr distillation (85-90 °C, ~0.5 mmHg) to obtain a white crystalline solid (1.99 g, 11.1 mmol; 64% yield). **Melting point:** 33-34 °C; **FT-IR (thin film):** 3071 (w), 1749 (s), 1415 (m), 1389 (m), 1284 (s), 1220 (s), 1162 (s), 1043 (m), 992 (m), 962 (m), 817 (m), 652 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.67 (d, *J* = 11.3 Hz; 1H), 6.10 (d, *J* = 11.3 Hz; 1H), 4.64 (q, *J* = 8.5 Hz;

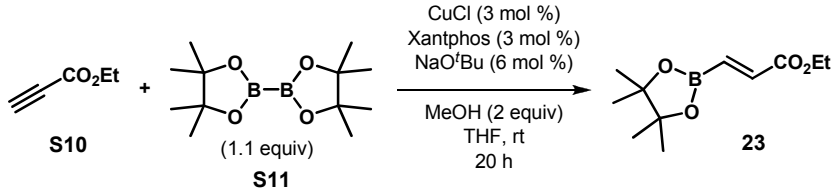
2H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 160.7, 135.8, 122.4 (q, *J* = 275 Hz), 113.6, 113.1, 61.1 (q, *J* = 37.0 Hz).

(E)-2,2,2-Trifluoroethyl 3-cyanoacrylate (**S9**):



To a solution of **S8** (1.07 g; 5.97 mmol) in 12 mL CH_2Cl_2, was added PPh_3 (313 mg; 1.19 mmol) and the resulting solution was stirred at rt for 48 h. The reaction mixture was concentrated and the residue was purified by silica gel column chromatography (10:1 to 3:1 hexanes/EtOAc, gradient) to obtain **S9** as a colorless oil (695 mg, 3.88 mmol; 65% yield, 76% yield based on recovered starting material). **FT-IR (thin film):** 3086 (w), 1749 (s), 1637 (w), 1415 (m), 1320 (m), 1284 (m), 1261 (s), 1162 (s), 1050 (m), 963 (s), 843 (w), 709 (w), 646 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.77 (d, *J* = 16.0 Hz; 1H), 6.59 (d, *J* = 16.0 Hz; 1H), 4.60 (q, *J* = 8.5 Hz; 2H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 161.6, 137.4, 122.4 (q, *J* = 275 Hz), 115.2, 114.7, 61.2 (q, *J* = 37.0 Hz).

(E)-Ethyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)acrylate (**23**):

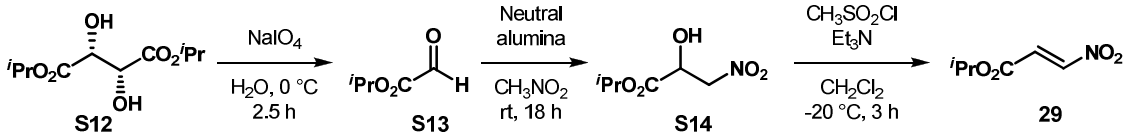


23 was prepared following the literature procedure.[3] In an oven- and flame-dried 50 mL Schlenk tube, CuCl (29.7 mg; 0.3 mmol), NaO^{t}Bu (58.0 mg; 0.6 mmol) and Xantphos (174 mg; 0.3 mmol) was placed and dried in vacuum. The flask was backfilled with nitrogen and 9 mL abs. THF was added. Resulting yellowish solution was stirred at rt for 60 min under nitrogen. A solution of bis(pinacolato)diboron **S11** (2.79 g; 11.0 mmol) in 7 mL abs. THF was added when the reaction mixture became dark brown and stirred at rt for 10 min. At this point ethyl propiolate **S10** (1.01 mL; 10.0 mmol) was added followed by abs. MeOH (0.81 mL; 20.0 mmol). The flask was sealed and the resulting mixture was stirred at rt for 20 h. The reaction mixture was filtered through a Celite® pad and washed with Et_2O. Filtrate was concentrated in vacuo to obtain a brown oil. Purification by silica gel column chromatography (10:1 to 8:1 hexanes/EtOAc) afforded **23** as a colorless oil (1.22 g, 5.4 mmol; 54% yield). **FT-IR (thin film):** 2980 (m), 2935 (w), 1723 (s), 1628 (m), 1468 (w), 1383 (m), 1344 (s), 1303 (s), 1260 (s), 1225 (m), 1166 (s), 1142 (s), 1112 (w), 1034 (m), 1002 (m),

(3) Lee, J.-E.; Kwon, J.; Yun, J. *Chem. Commun.* **2008**, 733-734.

969 (m), 902 (w), 847 (s), 725 (m), 671 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.75 (d, *J* = 18 Hz; 1H), 6.60 (d, *J* = 18 Hz; 1H), 4.19 (q, *J* = 7 .0 Hz; 2H), 1.25-1.28 (m; 15 H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 165.9, 138.7, 83.9, 60.5, 24.7, 14.1; **^{11}B-NMR (96 MHz, $CDCl_3$):** δ 29.7.

(E)-Isopropyl 3-nitroacrylate (**29**):



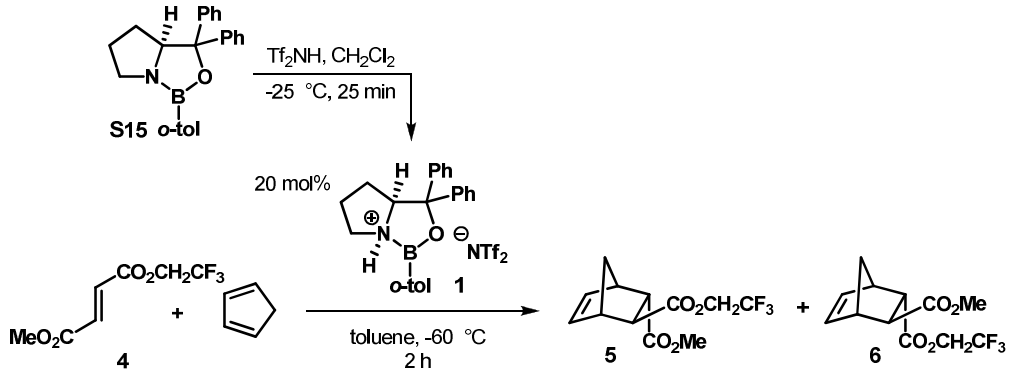
Diisopropyl-L-tatrate **S12** (5.00 g; 21.34 mmol) was placed in a 100 mL round-bottom flask together with 10 mL water and the resulting solution was cooled to 0 °C. $NaIO_4$ (5.94 g; 27.75 mmol) in 40 mL water was then added dropwise with vigorous stirring over 20 min. After the addition was complete, the resulting suspension was stirred at 0 °C for another 2 h. The reaction mixture was allowed to warm to ambient temperature and extracted with EtOAc (30 mL × 5). Combined extracts was dried over anh. Na_2SO_4 and concentrated in vacuo to obtain **S13** as a colorless oil (4.71 g) which was used immediately without further purification.

To a solution of this oil in 18 mL nitromethane at rt, neutral alumina (8.0 g) was added and the resulting suspension was stirred at rt for 18 h. The solid was filtered through a Celite® pad and washed with EtOAc. The filtrate was concentrated in vacuo to obtain a white solid. Purification by silica gel column chromatography (CH_2Cl_2 to 50:1 CH_2Cl_2/MeOH) afforded **S14** as a white solid (3.30 g, 18.63 mmol; 87% yield from **S12**). **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 5.20 (septet, *J* = 6 Hz; 1H), 4.77 (d, *J* = 4 Hz; 2H), 4.60 (t, *J* = 4 Hz; 1H), 3.41 (s; 1H), 1.32 (t, *J* = 6 Hz; 6H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 170.2, 71.4, 67.5, 21.6, 21.5.

S14 (3.04 g; 17.15 mmol) was taken in a 100 mL oven-dried round-bottom flask together with 32 mL abs. CH_2Cl_2 and the resulting solution was cooled to -20 °C under nitrogen. Methanesulfonyl chloride (4.0 mL; 51.45 mmol) was then added via syringe over 15 min followed by slow addition of Et_3N (7.17 mL; 51.45 mmol) over 5 min. The resulting yellow slurry was stirred at -20 °C for 2.5 h. Ice-cold water (150 mL) was the added to the reaction mixture and stirred vigorously at rt for 10 min. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (30 mL × 3). Combined organic layers was washed with water (50 mL × 5) and brine (50 mL), dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a yellow oil. Purification by silica gel column chromatography (10:1 hexanes/EtOAc) afforded **29** as a bright yellow oil (1.75 g, 11.0 mmol; 64% yield). **FT-IR (thin film):** 3112 (w), 2986 (m), 2940 (w), 1723 (s), 1643 (m), 1537 (s), 1469 (m), 1252 (s), 1282 (s), 1174 (s), 1146 (m), 990 (s), 948 (s), 903 (m), 820 (m), 762 (m), 673 (s); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 7.65 (d, *J* = 13.5 Hz; 1H), 7.05 (d, *J* = 13.5 Hz; 1H), 5.15 (septet, *J* = 6.5 Hz; 1H), 1.32 (d, *J* = 6.5 Hz; 6H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 162.1, 148.8, 128.1, 70.4, 21.6.

- **Catalytic enantioselective Diels-Alder reactions:**

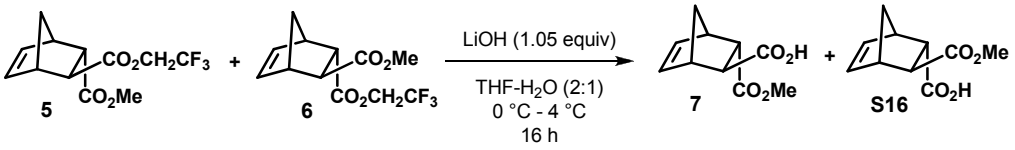
Methyl trifluoroethyl fumarate (**4**) *as the dienophile:*



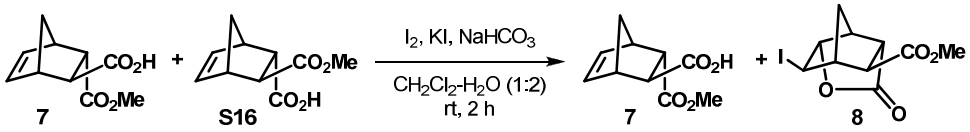
Catalyst precursor **S15** was either prepared following the previously reported procedure[4] or purchased from Sigma Aldrich Co. A 0.25M solution of oxazaborolidine **S15** in toluene (0.5 mL; 0.125 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and the solvent was removed under reduced pressure. Then 0.2 mL abs. toluene was added and the resulting clear solution was cooled to -25 °C (dry ice/iso-propanol) under positive pressure of nitrogen. A solution of Tf_2NH (0.2 mL of 0.5M in abs. toluene; 0.1 mmol) was added and the resulting solution was stirred at -25 °C for 25 min. The reaction mixture was cooled to -60 °C (dry ice/chloroform) and a solution of methyl trifluoroethyl fumarate **4** (106 mg; 0.5 mmol) in 0.3 mL abs. toluene was added. Cyclopentadiene (0.21 mL; 2.5 mmol) was then added down the wall of the flask over a period of two hours and stirred at -60 °C. The reaction was monitored by TLC and judged to be complete after 2 h. The reaction mixture was diluted with Et_2O (2 mL), brought to ambient temperature and filtered through a Celite® pad. The filtrate was concentrated in vacuo to obtain a pale yellow oil. ^{1}H-NMR analysis of the crude product revealed a 5:1 ratio of the two diastereomers. Purification by silica gel column chromatography (hexanes to 10:1 hexanes/EtOAc) afforded a colorless oil (138 mg, 0.496 mmol; 99% yield). **^{1}H-NMR (500 MHz, $CDCl_3$):** (*major*) δ 6.28-6.30 (m; 1H), 6.08-6.10 (m; 1H), 4.50-4.56 (m; 1H), 4.40-4.48 (m; 1H), 3.65 (s; 3H), 3.38-3.40 (m; 1H), 3.29 (br m; 1H), 3.16 (br m; 1H), 2.78-2.79 (m; 1H), 1.57-1.59 (m; 1H), 1.48-1.50 (m; 1H); (*minor*) δ 6.29-6.30 (m; 1H), 6.04-6.06 (m; 1H), 4.45-4.53 (m; 1H), 4.34-4.36 (m; 1H), 3.72 (s; 3H), 3.47-3.49 (m; 1H), 3.32 (br m; 1H), 3.16 (br m; 1H), 2.69-2.71 (m; 1H), 1.62-1.64 (m; 1H), 1.48-1.50 (m; 1H). Enantioselectivity of the two diastereomers were determined by GC analysis (Cyclosil-B column, 110 °C isothermal: τ_{minor} = 44.7 min, τ_{major} = 46.8 min for major diastereomer; τ_{major} = 46.2 min, τ_{minor} = 48.6 min for minor diastereomer) and found to be >99% *ee* for both diastereomers. See Supporting Information: Part B for GC chromatograms.

(4) Mukherjee, S.; Corey, E. J. *Org. Lett.* **2010**, *12*, in press.

Structure determination of **5** *and* **6***:*

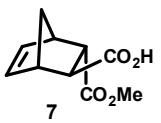


A solution of **5** and **6** (120 mg; 0.43 mmol) in 3:1 THF-H_2O (2 mL) was cooled to 0 °C with an ice-bath and 2M LiOH solution (0.23 mL; 0.46 mmol) was added dropwise over 1 h. After the addition was complete, reaction mixture was stirred at 0 °C (temperature varied between 0 and 4 °C) for 16 h. The reaction mixture was acidified with 2N HCl to pH ~2 and extracted with EtOAc (5 mL × 4). Combined organic layers were dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a colorless oil. Silica gel column chromatography (CH_2Cl_2 to 1:1 CH_2Cl_2/EtOAc) afforded a white crystalline solid (80 mg, 0.41 mmol; 95% yield). **^{1}H-NMR (500 MHz, $CDCl_3$):** (*major*) δ 6.27-6.29 (m; 1H), 6.06-6.08 (m; 1H), 3.64 (s; 3H), 3.36-3.38 (m; 1H), 3.26 (br m; 1H), 3.19 (br m; 1H), 2.71-2.72 (m; 1H), 1.59-1.61 (m; 1H), 1.46-1.48 (m; 1H); (*minor*) δ 6.26-6.28 (m; 1H), 6.12-6.14 (m; 1H), 3.70 (s; 3H), 3.41-3.43 (m; 1H), 3.29 (br m; 1H), 3.13 (br m; 1H), 2.64-2.66 (m; 1H), 1.59-1.62 (m; 1H), 1.45-1.48 (m; 1H).



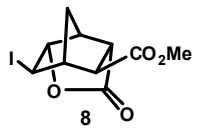
The solid (mixture of **7** and **S16**, 80 mg; 0.41 mmol) was taken in a 1:1 mixture of water and CH_2Cl_2 (2 mL) and $NaHCO_3$ (41 mg; 0.49 mmol) was added followed by a solution of I_2 (125 mg; 0.49 mmol) and KI (251 mg; 1.52 mmol) in water (1 mL). The resulting mixture was stirred at rt for 2 h and quenched with sat. $Na_2S_2O_3$ solution. The organic layer was separated and the aqueous layer was acidified with 2N HCl to pH~4. Aqueous layer was extracted with EtOAc (5 mL × 4) and combined organic layers were dried over anh. Na_2SO_4. Concentration in vacuo afforded a pale yellow oil. Purification by silica gel column chromatography (CH_2Cl_2 to 10:1 to 3:1 CH_2Cl_2/EtOAc) afforded **7** as a white crystalline solid (64 mg, 0.33 mmol) and **8** as a colorless oil (20 mg, 0.062 mmol).

(**7**): **Melting point:** 83-84 °C; **FT-IR (thin film):** 3250 (br), 2990 (w), 2953 (w), 1735 (s), 1700 (s), 1437 (m), 1333 (w), 1311 (w), 1268 (s), 1208 (br), 1114 (m), 1069 (w), 1024 (m), 909 (w), 865 (w), 721 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 11.5 (br; 1H), 6.27-6.29 (m; 1H), 6.08-6.09 (m; 1H), 3.65 (s; 3H), 3.37-3.38 (m; 1H), 3.27 (br m; 1H), 3.20 (br m; 1H), 2.72-2.73 (m; 1H), 1.61-1.62 (m; 1H), 1.47-1.49 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 180.4, 173.6, 137.5, 135.3, 51.9, 47.7, 47.6, 47.3, 47.2, 45.6; **HRMS (ESI+):**

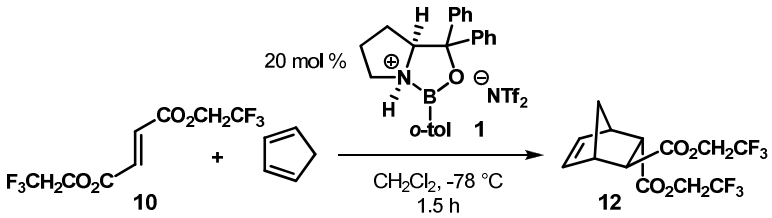


Calcd for $C_{10}H_{12}O_4Na$ ([M+Na]$^+$): 219.06278, Found: 219.06241; **Optical rotation:** $[\alpha]_D^{23}$ +147.6 ° (*c* 0.50, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*.

(**8**): **FT-IR (thin film):** 2994 (w), 2954 (w), 1795 (s), 1733 (s), 1459 (w), 1436 (m), 1349 (w), 1305 (m), 1244 (s), 1209 (s), 1176 (s), 1114 (m), 1003 (s), 958 (w), 936 (w), 919 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 5.13 (d, *J* = 5.0 Hz; 1H), 3.88 (d, *J* = 2.5 Hz; 1H), 3.73 (s; 3H), 3.20-3.21 (m; 1H), 3.09-3.10 (m; 1H), 3.02 (br m; 1H), 2.84 (br m; 1H), 2.31-2.34 (m; 1H), 1.95-1.98 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 177.2, 170.6, 88.4, 52.8, 50.4, 50.1, 46.1, 40.9, 35.1, 27.8; **HRMS (ESI+):** Calcd for $C_{10}H_{11}IO_4Na$ ([M+Na]$^+$): 344.95942, Found: 344.95945; **Optical rotation:** $[\alpha]_D^{23}$ -35.1 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*.

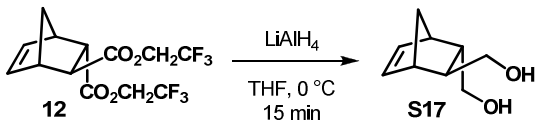


Bis(trifluoroethyl)fumarate (**10**) *as the dienophile:*



The same procedure as above was followed in CH_2Cl_2 at -78 °C with 0.5 mmol of **10**. Purification by silica gel column chromatography (hexanes to 5:1 hexanes/EtOAc) afforded a colorless oil (168 mg, 0.485 mmol; 97% yield). **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.33 (dd, *J* = 5.5, 3.0 Hz; 1H), 6.09 (dd, *J* = 5.5, 2.8 Hz; 1H), 4.32-4.62 (m; 4H), 3.49-3.50 (m; 1H), 3.36 (br m; 1H), 3.21 (br m; 1H), 2.80 (dd, *J* = 4.0, 1.5 Hz; 1H), 1.60-1.62 (m; 1H), 1.53-1.57 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 172.5, 171.3, 137.8, 135.0, 122.8 (q, *J* = 275 Hz), 60.5 (q, *J* = 36.5 Hz), 47.7, 47.6, 47.3, 46.9, 45.8; Spectral data are in agreement with the literature.[5] **Optical rotation:** $[\alpha]_D^{23}$ +85.7 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*. For determination of enantiopurity of **12**, see below.

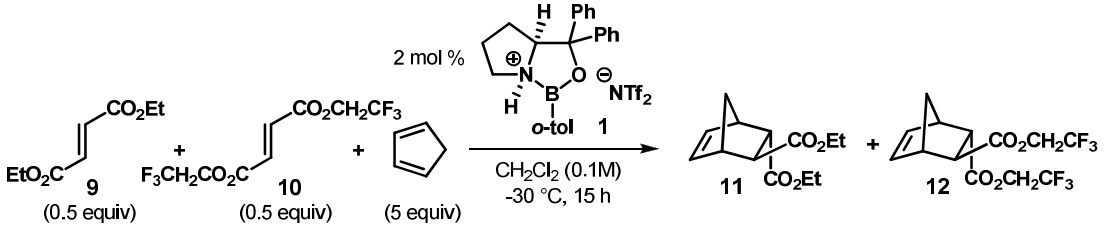
<u>*Determination of enantiomeric purity of* **12**:</u>



(5) Ryu, D. H.; Zhou, G.; Corey, E. J. *Org. Lett.* **2005**, *7*, 1633-1636.

In a 10 mL oven-dried round-bottom flask, **12** (50 mg; 0.14 mmol) was taken in 1 mL abs. THF and cooled to 0 °C under positive pressure of nitrogen. A 2.0M solution of $LiAlH_4$ in THF (0.14 mL; 0.28 mmol) was then added over 10 min. After stirring for another 5 min, EtOAc was added dropwise to the reaction mixture at 0 °C and slowly brought to rt Sat. Na_2SO_4 solution was added and extracted with EtOAc (5 mL × 3). Combined organic layers were washed with brine (10 mL), dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a colorless oil. Silica gel column chromatography (CH_2Cl_2 to 10:1 CH_2Cl_2/MeOH) afforded **S17** as a colorless oil (20 mg, 0.13 mmol; 93% yield). **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.22 (dd, *J* = 5.3, 3.3 Hz; 1H), 5.96 (dd, *J* = 5.3, 2.5 Hz; 1H), 3.75 (dd, *J* = 9.6, 5.3 Hz; 1H), 3.63 (dd, *J* = 9.6, 5.0 Hz; 1H), 3.39 (t, *J* = 10 Hz; 1H), 3.26 (br, 2H), 3.01 (t, *J* = 10 Hz; 1H), 2.81 (br m; 1H), 2.58 (br m; 1H), 1.90-1.94 (m; 1H), 1.42-1.46 (m; 2H), 1.27-1.31 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 137.9, 133.4, 66.5, 65.9, 47.9, 47.1, 46.9, 44.6, 44.5; Spectral data are in agreement with the literature.[6] **Optical rotation:** $[\alpha]_D^{23}$ -23.6 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of 99% *ee* {Lit.[7] -23.1 ° (*c* 1.01, $CHCl_3$)}. The enantiopurity was determined by GC analysis (Cyclosil-B column, 140 °C, 2 °C/min to 190 °C, τ_{major} = 20.8 min, τ_{minor} = 21.2 min). See Supporting Information: Part B for GC chromatograms.

Intermolecular competition experiment between diethylfumarate (**9**) *and bis-(trifluoroethyl)fumarate* (**10**) *in asymmetric Diels-Alder Reaction:*

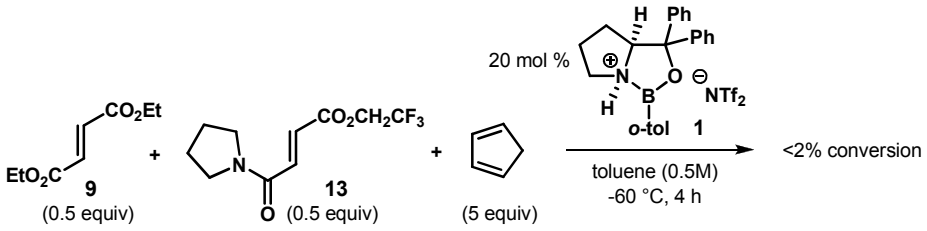


A 0.25M solution of oxazaborolidine **S15** in toluene (0.05 mL; 0.0125 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and the solvent was removed under reduced pressure. Then 0.5 mL abs. CH_2Cl_2 was added and the resulting clear solution was cooled to -30 °C (dry ice/iso-propanol) under positive pressure of nitrogen. A solution of Tf_2NH (0.1 mL of 0.1M in abs. CH_2Cl_2; 0.1 mmol) was added and the resulting solution was stirred at -30 °C for 25 min. The reaction mixture then diluted with 2 mL abs. CH_2Cl_2 and stirred at -30 °C for 10 min before adding a mixture of **9** (43 mg; 0.25 mmol) and **10** (70 mg; 0.25 mmol) in 2.2 mL abs. CH_2Cl_2. After stirring the reaction mixture for another 10 min at -30 °C, cyclopentadiene (0.21 mL; 2.5 mmol) was added down the wall of the flask over one min. Final concentration of the reaction mixture was 0.1M with respect to **9** and **10**, together. After 15 min, the reaction was quenched with Et_3N (0.05 mL), diluted

(6) Maruoka, K.; Akakura, M.; Saito, S.; Ooi, T.; Yamamoto, H. *J. Am. Chem. Soc.* **1994**, *116*, 6153-6158.
(7) Achmatowicza, M.; Chapuisa, C.; Rzepeckib, P.; Jurczaka, J. *Helv. Chim. Acta.* **1999**, *82*, 182-190.

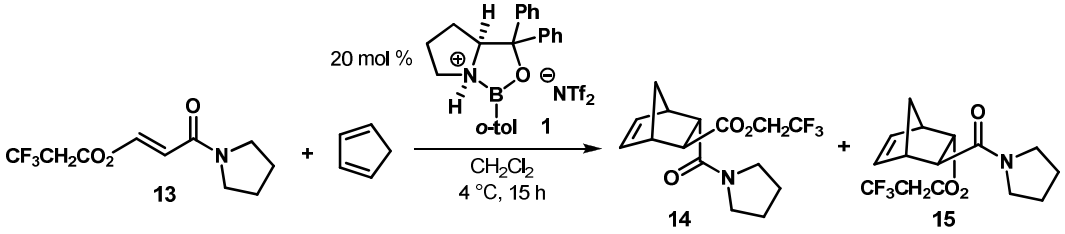
with Et_2O (3 mL) and concentrated in vacuo to obtain a pale yellow oil. Conversions were determined by the ^{1}H-NMR analysis of the crude product. Enantioselectivity of **11** was determined by GC analysis (Cyclosil-B column, 110 °C for 10 min, then 1 °C/min to 150 °C: τ_{minor} = 46.3 min, τ_{major} = 46.6 min for major diastereomer; τ_{major} = 46.2 min, τ_{minor} = 48.6 min for minor diastereomer) of a sample obtained after prep-TLC (10:1 hexanes/EtOAc × 2) and found to be 86% *ee*. Enantioselectivity of **12** was determined by converting it to the diol **S17** (see above) after column chromatographic purification of **12** (silicalgel column using CH_2Cl_2) and was found to be *racemic*.

Intermolecular competition experiment between **9** *and* **13** *in asymmetric Diels-Alder Reaction:*



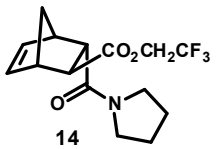
A 0.25M solution of oxazaborolidine **S15** in toluene (0.5 mL; 0.125 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and cooled to -25 °C (dry ice/chloroform) under positive pressure of nitrogen. A solution of Tf_2NH (0.2 mL of 0.5M in abs. toluene; 0.10 mmol) was added and the resulting solution was stirred at -25 °C for 25 min. The reaction mixture was then cooled to -60 °C (dry ice/chloroform) and a mixture of **9** (43 mg; 0.25 mmol) and **13** (63 mg; 0.25 mmol) in 0.3 mL abs. toluene was added. Cyclopentadiene (0.21 mL; 2.5 mmol) was added down the wall of the flask over a period of 1 h. The reaction was monitored by TLC and no conversion was observerd even after 4 h.

(E)-2,2,2-Trifluoroethyl 4-oxo-4-(pyrrolidin-1-yl)but-2-enoate (**13**) *as the dienophile:*



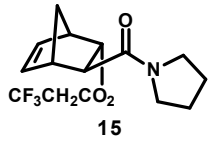
The same procedure as above was followed in CH_2Cl_2 at 4 °C with 0.3 mmol of **13**. ^{1}H-NMR analysis of the crude product revealed a 5:1 ratio of the two diastereomers **14** and **15**, respectively. Purification by silica gel column chromatography (hexanes to 2:1 hexanes/EtOAc) afforded **14** as a white crystalline solid (75 mg) and **15** as a colorless oil (15 mg) (95% yield).

(**14**): **Melting point:** 66 °C; **FT-IR (thin film):** 2976 (m), 2877 (w), 1752 (s), 1633 (s), 1434 (s), 1334 (m), 1281 (s), 1159 (s), 1115 (s), 1083 (w), 977 (m), 914 (w), 865 (m), 723 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.29 (dd, *J* = 5.5, 3.0 Hz; 1H), 6.06 (dd, *J* = 5.5, 2.8 Hz; 1H), 4.44-4.49 (m; 1H), 4.31-4.37 (m; 1H), 3.67-3.68 (m; 1H), 3.40-3.52 (m; 4H), 3.30 (br m; 1H), 2.91 (br m; 1H), 2.68-2.69 (m; 1H), 1.93-1.98 (m; 3H), 1.81-1.88 (m; 2H), 1.40-1.42 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 172.5, 171.4, 138.1, 135.2, 122.9 (q, *J* = 275 Hz), 60.0 (q, *J* = 36.5 Hz), 47.7, 47.3, 46.6, 46.5, 46.3, 46.1, 45.6, 29.1, 24.2. Enantiopurity was determined by HPLC analysis (Chiralcel-OJ column, 220 nm, 90:10 hexanes/*i*-PrOH, 1.0 mL/min, τ = 5.4 and 8.9 min) and found to be *racemic*. See Supporting Information: Part B for HPLC chromatograms.



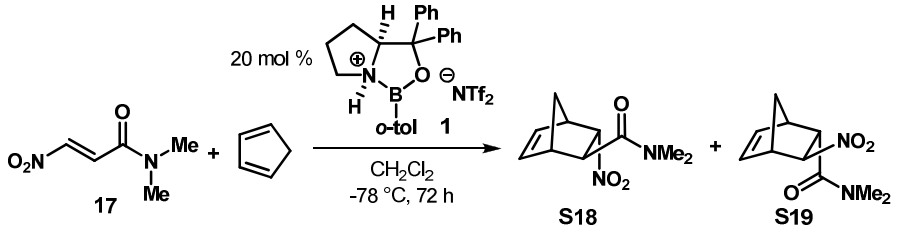
14

(**15**): **FT-IR (thin film):** 2974 (m), 2876 (w), 1747 (s), 1635 (s), 1435 (s), 1358 (m), 1337 (s), 1280 (s), 1144 (s), 1076 (w), 975 (m), 861 (m), 693 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.33 (dd, *J* = 5.8, 3.5 Hz; 1H), 6.05 (dd, *J* = 5.8, 3.0 Hz; 1H), 4.44-4.54 (m; 2H), 3.53-3.58 (m; 2H), 3.44-3.49 (m; 1H), 3.35-3.40 (m; 2H), 3.21 (br m; 1H), 3.18 (br m; 1H), 3.01-3.02 (m; 1H), 1.95-2.00 (m; 2H), 1.82-1.88 (m; 2H), 1.58-1.60 (m; 1H), 1.48-1.50 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 173.7, 170.4, 136.6, 134.3, 123.0 (q, *J* = 275 Hz), 60.3 (q, *J* = 36.5 Hz), 48.1, 47.8, 47.0, 46.9, 46.4, 46.2, 45.3, 26.2, 24.1. Enantiopurity was determined by HPLC analysis (Chiralcel-OJ column, 220 nm, 90:10 hexanes/*i*-PrOH, 1.0 mL/min, τ = 5.9 and 9.8 min) and found to be *racemic*. See Supporting Information: Part B for HPLC chromatograms.



15

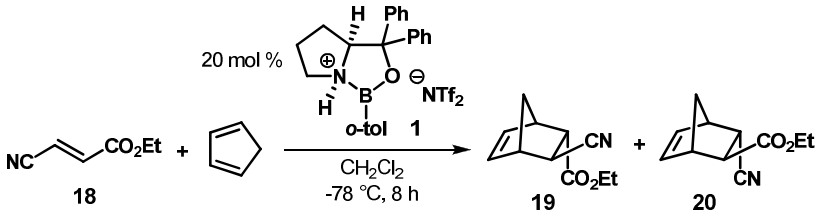
(E)-N,N-dimethyl-3-nitroacrylamide (**17**) *as the dienophile:*



Same procedure as described previously was followed in CH_2Cl_2 at -78 °C with 0.3 mmol of **17**. Reaction did not proceed to completion even after 72 h and was stopped at ~90% conversion. ^{1}H-NMR analysis of the crude product revealed a >20:1 ratio of the two diastereomers **S18** and **S19**, respectively. Purification by silica gel column chromatography (3:1 to 1.5:1 hexanes/EtOAc gradient) afforded **S18** as a pale yellow oil (85 mg, 0.40 mmol; 80% yield). **FT-IR (thin film):** 2950 (m), 1638 (s), 1534 (s), 1497 (m), 1455 (w), 1399 (m), 1378 (s), 1333 (m), 1258 (m), 1147 (s), 1118 (m), 1059 (w), 958 (w), 913 (m), 870 (m), 803 (m), 774 (m), 712 (s), 680 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.46 (dd, *J* = 5.5, 3.0 Hz; 1H), 6.09 (dd, *J* = 5.5, 2.8 Hz; 1H), 5.63-5.65 (m; 1H),

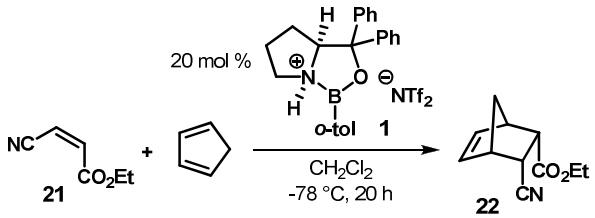
3.55 (br m; 1H), 3.12-3.13 (m; 1H), 3.09 (s; 3H), 2.97 (s; 3H), 2.95 (br m; 1H), 1.89-1.91 (m; 1H), 1.52-1.54 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 170.7, 138.9, 134.2, 88.2, 47.7, 46.9, 46.6, 45.3, 37.2, 35.9. Enantiopurity was determined by HPLC analysis (Chiralpak-AD column, 220 nm, 90:10 hexanes/*i*-PrOH, 1.0 mL/min, τ = 8.8 and 11.2 min) and found to be *racemic*. See Supporting Information: Part B for HPLC chromatograms.

(E)-Ethyl 3-cyanoacrylate (**18**) *as the dienophile*:



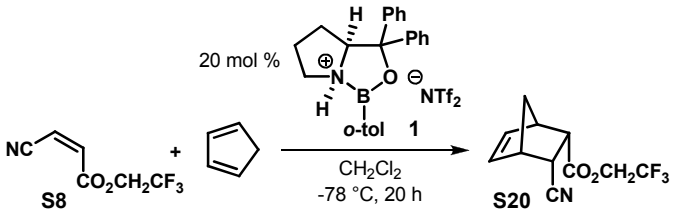
A 0.25M solution of oxazaborolidine **Sx** in toluene (0.5 mL; 0.125 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and the solvent was removed under reduced pressure. Then 0.3 mL abs. CH_2Cl_2 was added and the resulting clear solution was cooled to -25 °C (dry ice/iso-propanol) under positive pressure of nitrogen. A solution of Tf_2NH (0.2 mL of 0.5M in abs. CH_2Cl_2; 0.1 mmol) was added and the resulting solution was stirred at -25 °C for 25 min. The reaction mixture was then cooled to -78 °C and a solution of **18** (63 mg; 0.5 mmol) in 0.5 mL abs. CH_2Cl_2 was added. Cyclopentadiene (0.21 mL; 2.5 mmol) was then added down the wall of the flask over a period of 2 h and stirred at -78 °C for another 6 h. The reaction mixture was diluted with Et_2O (2 mL), brought to ambient temperature and filtered through a Celite® pad. The filtrate was concentrated in vacuo to obtain a colorless oil. ^{1}H-NMR analysis of the crude product revealed a 10:1 ratio of the two diastereomers **19** and **20**, respectively. Purification by silica gel column chromatography (10:1 hexanes/EtOAc) afforded a colorless oil (91 mg, 0.475 mmol; 95% yield). Enantioselectivity of **19** and **20** were determined by GC analysis (Cyclosil-B column, 135 °C isothermal: τ_{major} = 30.6 min, τ_{minor} = 36.1 min for **19**; τ_{minor} = 29.5 min, τ_{major} = 31.1 min for **20**) and found to be 97% *ee* for **19** and 75% *ee* for **20**. See Supporting Information: Part B for GC chromatograms. **^{1}H-NMR (500 MHz, $CDCl_3$):** δ (**19**) 6.21 (dd, *J* = 5.8, 3.3 Hz; 1H), 6.05 (dd, *J* = 5.8, 3.0 Hz; 1H), 4.10-4.15 (m; 2H), 3.38 (br m; 1H), 3.27 (br m; 1H), 3.25 (t, *J* = 4.0 Hz; 1H), 2.70 (dd, *J* =4.0, 2.0 Hz; 1H), 1.72-1.74 (m; 1H), 1.65-1.67 (m; 1H), 1.25 (t, *J* = 7.3 Hz; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ (**19**) 171.1, 136.0, 134.8, 122.1, 61.2, 50.1, 48.3, 48.2, 45.9, 31.1, 14.1.

(Z)-Ethyl 3-cyanoacrylate (**21**) *as the dienophile*:



Same procedure as for the reaction using **18** as the dienophile was followed on a 0.50 mmol scale. ^{1}H-NMR analysis of the crude product revealed a 8:1 *endo*/*exo* ratio in favor of the *endo*-product **22**. After purification using silica gel column chromatography (10:1 to 5:1 hexanes/EtOAc), product (**22**) was obtained as a colorless oil (80 mg, 0.42 mmol; combined yield = 94%). **FT-IR (thin film):** 2985 (m), 2878 (w), 2240 (m), 1735 (s), 1455 (w), 1373 (m), 1334 (m), 1251 (m), 1226 (w), 1188 (s), 1144 (w), 1096 (w), 1042 (s), 912 (w), 835 (w), 767 (w), 738 (m), 639 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.46 (dd, *J* = 5.8, 2.8 Hz; 1H), 6.31 (dd, *J* = 5.8, 2.5 Hz; 1H), 4.13-4.19 (m; 2H), 3.23-3.30 (m; 4H), 1.56-1.57 (m; 1H), 1.30-1.32 (m; 1H), 1.27 (t, *J* = 7.3 Hz; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 170.4, 137.9, 133.9, 119.9, 61.1, 48.6, 47.9, 46.8, 44.9, 33.1, 14.1; **HRMS (ESI+):** Calcd for $C_{11}H_{14}NO_2$ ($[M+H]^+$): 192.10191, Found: 192.10199; Calcd for $C_{11}H_{13}NO_2Na$ ($[M+Na]^+$): 214.08385, Found: 214.08411; **Optical rotation:** $[\alpha]_D^{23}$ -50.5 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of 92% *ee*. Enantipurity was determined by GC analysis (Cyclosil-B column, 150 °C isothermal: τ_{minor} = 25.5 min, τ_{major} = 27.1 min). See Supporting Information: Part B for GC chromatograms.

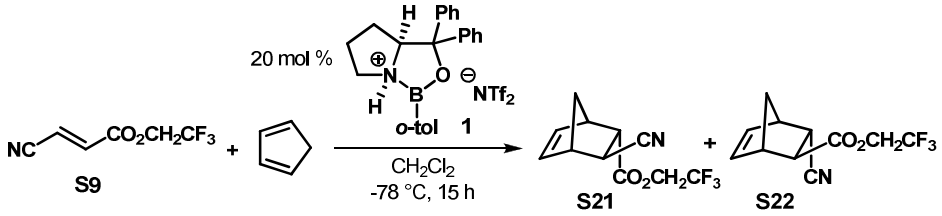
(Z)-2,2,2-Trifluoroethyl 3-cyanoacrylate (**S8**) *as the dienophile*:



Same procedure as above was followed on a 0.50 mmol scale. ^{1}H-NMR analysis of the crude product revealed a 6:1 *endo*/*exo* ratio in favor of the *endo*-product **S20**. After purification using silica gel column chromatography (10:1 to 5:1 hexanes/EtOAc), **S20** was obtained as a colorless oil (102 mg, 0.42 mmol; combined yield = 92%). **FT-IR (thin film):** 2986 (w), 1758 (s), 1453 (w), 1412 (m), 1337 (m), 1280 (s), 1157 (s), 1064 (m), 988 (m), 912 (w), 835 (m), 769 (w), 739 (m), 666 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.41 (dd, *J* = 6.0, 3.0 Hz; 1H), 6.34 (dd, *J* = 6.0, 2.8 Hz; 1H), 4.58-4.66 (m; 1H), 4.29-4.36 (m; 1H), 3.31-3.39 (m; 4H), 1.58-1.61 (m; 1H), 1.34-1.36 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 168.9, 137.2, 134.6, 122.7 (q, *J* = 275 Hz), 119.4, 60.5 (q, *J* =

36.5 Hz), 48.0, 47.9, 46.8, 45.1, 33.0; Enantipurity was determined by GC analysis (Cyclosil-B column, 140 °C, 1 °C/min to 160 °C, 160 °C for 2 min: τ_{minor} = 18.9 min, τ_{major} = 21.2 min) and found to be 62% *ee*. See Supporting Information: Part B for GC chromatograms.

(E)-2,2,2-Trifluoroethyl 3-cyanoacrylate (**S9**) *as the dienophile*:

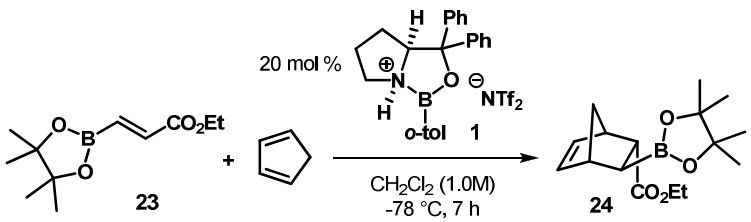


Same procedure was above was followed on a 0.5 mmol scale. ^{1}H-NMR analysis of the crude product revealed a 3.5:1 ratio of the two diastereomers **S21** and **S22**, respectively. Purification by silica gel column chromatography (hexanes to 8:1 hexanes/EtOAc) afforded a colorless oil (114 mg, 0.46 mmol; 92% yield). Enantioselectivity of **S21** and **S22** were determined by GC analysis (Cyclosil-B column, 120 °C, 1 °C/min to 150 °C, 150 °C for 1 min: τ_{major} = 23.5 min, τ_{minor} = 28.7 min for **S21**; τ_{minor} = 23.2 min, τ_{major} = 23.9 min for **S22**) and found to be 42% *ee* for **S21** and 15% *ee* for **S22**. See Supporting Information: Part B for GC chromatograms.

(**S21**): **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.23 (dd, *J* = 5.5, 3.0 Hz; 1H), 6.03 (d, *J* = 5.5, 2.8 Hz; 1H), 4.53-4.62 (m; 1H), 4.32-4.40 (m; 1H), 3.43 (br m; 1H), 3.34-3.35 (m; 1H), 3.30 (br m; 1H), 2.69-2.70 (m; 1H), 1.74-1.76 (m; 1H), 1.68-1.1.71 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 169.7, 136.5, 134.4, 122.6 (q, *J* = 275 Hz), 121.5, 60.5 (q, *J* = 36.5 Hz), 49.6, 48.3, 48.2, 46.1, 31.2.

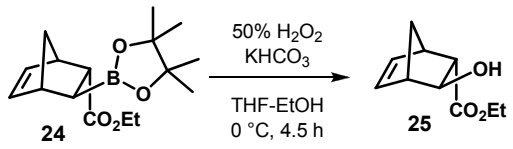
(**S22**): **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.43 (dd, *J* = 5.3, 3.3 Hz; 1H), 6.35 (dd, *J* = 5.3, 2.5 Hz; 1H), 4.56-4.60 (m; 1H), 4.40-4.46 (m; 1H), 3.43 (br m; 1H), 3.31-3.33 (m; 1H), 3.24 (br m; 1H), 2.63-2.64 (m; 1H), 1.55-1.57 (m; 1H), 1.49-1.51 (m; 1H); **^{13}C-NMR (125 MHz, $CDCl_3$):** 171.0, 138.3, 135.7, 121.5 (q, *J* = 275 Hz), 121.0, 60.5 (q, *J* = 36.5 Hz), 49.8, 47.8, 46.0, 45.9, 32.1.

(E)-Ethyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)acrylate (**23**) *as the dienophile*:



A 0.25M solution of oxazaborolidine **Sx** in toluene (0.5 mL; 0.125 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and the solvent was removed under reduced pressure. Then 0.2 mL abs. CH_2Cl_2 was added and the resulting clear solution was cooled to -25 °C (dry ice/iso-propanol) under positive pressure of nitrogen. A solution of Tf_2NH (0.2 mL of 0.5M in abs. CH_2Cl_2; 0.1 mmol) was added and the resulting solution was stirred at -25 °C for 25 min. Solvent was then removed under reduced pressure at -25 °C. A solution of **23** (113 mg; 0.5 mmol) in 0.4 mL abs. CH_2Cl_2 was added to the residue and the solvent was removed again at -25 °C. The residue was taken in 0.3 mL abs. CH_2Cl_2 and the reaction mixture was cooled to -78 °C (dry ice/iso-propanol). Cyclopentadiene (0.21 mL; 2.5 mmol) was then added down the wall of the flask over a period of 2 h and stirred at -78 °C for another 5 h. The reaction mixture was diluted with Et_2O (2 mL), brought to ambient temperature and filtered through a Celite® pad. The filtrate was concentrated in vacuo to obtain a pale yellow oil. Purification by silica gel column chromatography (hexanes to 5:1 hexanes/EtOAc) afforded **24** as a white solid (134 mg, 0.46 mmol; 92% yield). **Melting point:** 34-35 °C; **FT-IR (thin film):** 3060 (w), 2978 (m), 2935 (w), 1732 (s), 1468 (w), 1408 (w), 1370 (s), 1317 (s), 1269 (m), 1253 (m), 1192 (m), 1167 (m), 1143 (s), 1107 (s), 1059 (w), 1032 (m), 973 (s), 909 (m), 852 (s), 729 (s), 690 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.25 (dd, *J* = 5.8, 3.3 Hz; 1H), 5.85 (dd, *J* = 5.8, 2.5 Hz; 1H), 4.00-4.09 (m; 2H), 3.21 (br m; 1H), (3.06, *J* = 4.8, 3.8 Hz; 1H), 2.92 (br m; 1H), 1.16-1.32 (m; 17 H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 174.8, 139.2, 131.4, 83.3, 60.0, 48.6, 46.4, 46.0, 45.3, 24.7, 24.6, 14.2; **^{11}B-NMR (96 MHz, $CDCl_3$):** δ 34.0; **HRMS (ESI+):** Calcd for $C_{16}H_{26}BO_4$ ($[M+H]^+$): 293.19187, Found: 293.19135; Calcd for $C_{16}H_{25}BO_4$ ($[M+Na]^+$): 315.17381, Found: 315.17324; **Optical rotation:** $[\alpha]_D^{23}$ +100.0 ° (*c* 2.00, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*. See below for the determination of enantiomeric purity.

Determination of enantiomeric purity of **24**:



In a 25 mL round-bottom flask, **24** (80 mg; 0.27 mmol) was placed together with 3:1 THF-EtOH (2.5 mL) and the resulting solution was cooled to 0 °C. A 2.0M aqeous $KHCO_3$ solution (0.27 mL; 0.54 mmol) was added followed by slow addition of H_2O_2 (0.062 mL; 1.08 mmol) over 10 min. The resulting mixture was stirred at 0 °C for 4.5 h. The reaction was quenched with sat. $Na_2S_2O_3$ and extracted with EtOAc (5 mL × 3). Combined organic layers was washed with water (10 mL) and brine (10 mL), dried over anh. Na_2SO_4 and concentrated to obtain a colorless oil. Purified by silica gel column chromatography (5:1 to 2:1 hexanes/EtOAc) afforded **25** as a colorless oil (47 mg, 0.26 mmol; 96% yield). **FT-IR (thin film):** 3432 (br), 3066 (w), 2979 (m), 2941 (w), 2874 (w), 1731

(w), 1713 (s), 1448 (m), 1370 (m), 1327 (m), 1255 (m), 1187 (s), 1114 (s), 1096 (m), 1030 (s), 997 (w), 979 (m), 917 (w), 858 (m), 822 (w), 777 (w), 716 (s), 695 (s); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.14 (dd, *J* = 5.8, 2.8 Hz; 1H), 6.07 (dd, *J* = 5.8, 3.3 Hz; 1H), 4.06-4.13 (m; 3H), 3.09 (br m; 1H), 2.82 (br s; 1H), 2.77 (br m; 1H), 2.63 (t, *J* = 3.0 Hz; 1H), 1.82-1.90 (m; 1H), 1.63-1.65 (m; 1H), 1.23 (t, *J* = 7.0 Hz; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 173.6, 137.1, 134.6, 75.5, 60.4, 55.0, 50.4, 46.3, 44.0, 14.2; **HRMS (ESI+):** Calcd for $C_{10}H_{14}O_3Na$ ($[M+Na]^+$): 205.08352, Found: 205.08362; **Optical rotation:** $[\alpha]_D^{23}$ +137.0 ° (*c* 2.00, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*. The enantiomeric purity was determined by GC analysis (Cyclosil-B column, 150 °C for 5 min, 1 °C/min to 160 °C, 160 °C for 5 min: τ_{minor} = 14.1 min, τ_{major} = 15.1 min). See Supporting Information: Part B for GC chromatograms.

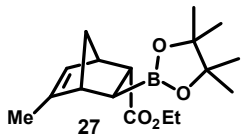
Dehydration of **25** *to the diene* **26**:

Alcohol **25** (25 mg; 0.14 mmol) was placed in a 10 mL flame-dried round-bottom flask together with 0.5 mL abs. CH_2Cl_2 and cooled to -20 °C under nitrogen. Methanesulfonyl chloride (0.013 mL; 0.168 mmol) was then added followed by Et_3N (0.023 mL; 0.168 mmol). The resulting mixture was stirred at -20 °C for 15 min. Water and CH_2Cl_2 was added to the reaction mixture and allowed to warm to ambient temperature. Organic layer was separated and the aqueous layer was extracted with CH_2Cl_2 (5 mL × 2). The combined organic layer was dried over anh. Na_2SO_4 and concentrated in vacuo to obtain **S23** as a pale yellow oil (36 mg) which was pure enough to be used as such for the next step. **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.22 (dd, *J* = 5.9, 2.8 Hz; 1H), 6.09 (dd, *J* = 5.8, 3.5 Hz; 1H), 4.81 (m; 1H), 4.05-4.17 (m; 2H), 3.19 (br m; 1H), 3.15 (br m; 1H), 3.07 (s; 3H), 2.94-2.96 (m; 1H), 1.86-1.88 (m; 1H), 1.74-1.76 (m; 1H), 1.24 (t, *J* = 7.0 Hz; 3H).

S23 (36 mg; 0.14 mmol) was taken in 0.5 mL abs. THF in a 10 mL round-bottom flask and cooled to -78 °C under nitrogen. A 1.0M solution of LHMDS in THF (0.35 mL; 0.35 mmol) was added via syringe over 20 min. Sat. NH_4Cl solution was added to the reaction mixture and allowed to warm to ambient temperature. The resulting mixture was extracted with Et_2O (5 mL × 3). The combined extracts was dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a pale yellow oil. Purification by silica gel column chromatography (5:1 hexanes/EtOAc) afforded **26** as a colorless oil (20 mg, 0.12 mmol; 87% yield from **25**). **FT-IR (thin film):** 3031 (w), 2976 (w), 2920 (m), 2850 (w), 1707 (s), 1595 (m), 1556 (m), 1463 (w), 1367 (m), 1318 (s), 1289 (s), 1238 (s), 1151 (s), 1097 (s), 1061 (s), 1023 (m), 876 (w), 759 (s), 724 (w), 695 (s); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 7.64 (d, *J* = 3.0 Hz; 1H), 6.93 (dd, *J* = 5.0, 3.0 Hz; 1H), 6.74 (dd, *J* = 5.0, 3.3 Hz; 1H), 4.20 (q, *J* = 7.0 Hz; 2H), 3.91 (br m; 1H), 3.72 (br m; 1H), 2.12-2.17 (m; 2H), 1.30 (t, *J* = 7.0; 3H); **^{13}C-NMR**

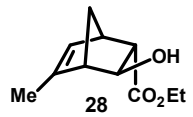
(125 MHz, $CDCl_3$): δ 165.0, 155.5, 149.8, 143.7, 141.8, 74.4, 60.2, 51.5, 50.0, 14.3; **HRMS (ESI+):** Calcd for $C_{10}H_{13}O_2$ ($[M+H]^+$): 165.09101, Found: 165.09144; **Optical rotation:** $[\alpha]_D^{23}$ -40.0 ° (*c* 0.30, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*. The enantiomeric purity was determined by GC analysis (Cyclosil-B column, 120 °C isotherm: τ_{minor} = 13.2 min, τ_{major} = 14.3 min). See Supporting Information: Part B for GC chromatograms.

(**27**): Same procedure as above was followed in 0.5 mmol scale and the reaction was complete within 2 h. Purification by silica gel column chromatography (hexanes to 10:1 hexanes/EtOAc) afforded pure **27** as a colorless oil (150 mg, 0.49 mmol; 98% yield). **FT-IR (thin film):** 2977 (m), 2933 (w), 1869 (w), 1733 (s), 1626 (w), 1445 (m), 1407 (w), 1370 (s), 1315 (s), 1262 (s), 1213 (m), 1166 (s), 1143 (s), 1105 (s), 1060 (w), 1035 (m), 970 (m), 912 (w), 894 (w), 855 (s), 786 (m), 667 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 5.36 (br m; 1H), 3.99-4.05 (m; 2H), 3.06-3.08 (m; 2H), 2.65 (br m; 1H), 1.74 (m; 3H), 1.33-1.36 (m; 1H), 1.27-1.29 (m; 1H), 1.19-1.25 (m; 15 H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 175.0, 149.5, 124.5, 83.3, 59.9, 50.0, 48.3, 48.2, 47.1, 24.7, 24.6, 14.9, 14.2; **^{11}B-NMR (96 MHz, $CDCl_3$):** δ 34.1; **HRMS (ESI+):** Calcd for $C_{17}H_{28}BO_4$ ($[M+H]^+$): 307.20752, Found: 307.20761; Calcd for $C_{17}H_{27}BO_4Na$ ($[M+Na]^+$): 329.18946, Found: 329.18973; **Optical rotation:** $[\alpha]_D^{23}$ +112.0 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of 99% *ee*. The enantiomeric purity was determined by converting to the corresponding alcohol (**28**) and GC-analysis (see below).



27

(**28**): Same procedure as above was followed in 0.18 mmol scale. Purification by silica gel column chromatography (5:1 to 2:1 hexanes/EtOAc) afforded pure **28** as a colorless oil (34 mg, 0.17 mmol; 94% yield). **FT-IR (thin film):** 3436 (br), 2969 (m), 2938 (w), 2874 (w), 1731 (s), 1714 (s), 1630 (w), 1444 (m), 1370 (m), 1315 (w), 1255 (s), 1185 (s), 1112 (s), 1049 (s), 1023 (s), 982 (m), 930 (m), 907 (w), 857 (w), 824 (m), 785 (w); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 5.60 (br m; 1H), 4.04-4.09 (m; 3H), 2.96-2.98 (m; 1H), 2.63-2.64 (m; 1H), 2.51 (br m; 1H), 2.40 (br s; 1H), 1.81-1.83 (m; 1H), 1.70-1.72 (m; 3H), 1.63-1.66 (m; 1H), 1.19-1.23 (m; 3H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 173.7, 145.0, 129.1, 75.3, 60.3, 57.2, 55.2, 46.0, 44.9, 15.3, 14.2; **HRMS (ESI+):** Calcd for $C_{11}H_{16}O_3Na$ ($[M+Na]^+$): 219.09917, Found: 219.09900; **Optical rotation:** $[\alpha]_D^{23}$ +146.0 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of 99% *ee*. The enantiomeric purity was determined GC analysis (Cyclosil-B column, 150 °C for 5 min, 1 °C/min to 170 °C, 170 °C for 5 min, τ_{minor} = 13.9 min, τ_{major} = 14.7 min). See Supporting Information: Part B for GC chromatograms.



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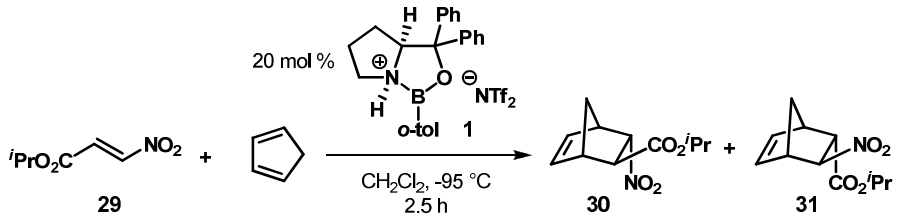
(E)-Isopropyl 3-nitroacrylate (**29**) *as the dienophile*:

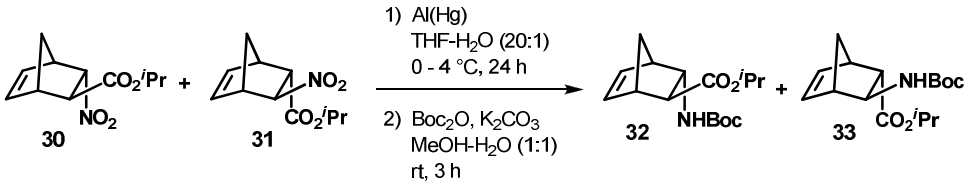


A 0.25M solution of oxazaborolidine **Sx** in toluene (1.5 mL; 0.375 mmol) was placed in a 10 mL oven- and flame-dried Schlenk tube and the solvent was removed under reduced pressure. Then 1.0 mL abs. CH_2Cl_2 was added and the resulting clear solution was cooled to -25 °C (dry ice/iso-propanol) under positive pressure of nitrogen. A solution of Tf_2NH (0.6 mL of 0.5M in abs. CH_2Cl_2; 0.30 mmol) was added followed by 0.3 mL abs. CH_2Cl_2 and the resulting solution was stirred at -25 °C for 25 min. The resulting mixture was then cooled to -95 °C (hexanes/liq. N_2) and cyclopentadiene (0.62 mL; 7.50 mmol) was slowly added along the wall of the flask over a few mins. After 10 min, a solution of **29** (239 mg; 1.50 mmol) in 1.0 ml abs. CH_2Cl_2 was added slowly over 2.5 h. The reaction was found to be complete immediately after the addition was complete (monitored by TLC). Methanol (0.5 mL) was added to the reaction mixture followed by Et_2O (3 mL) and allowed to warm to ambient temperature, filtered through a Celite® pad and the filatrate was concentrated in vacuo to obtain an orange oil. ^{1}H-NMR analysis of the crude product revealed a 1.5:1 ratio of the two diastereomers **30** and **31**, respectively. Purification by silica gel column chromatography (hexanes to 10:1 hexanes/EtOAc) afforded a colorless oil (318 mg, 1.41 mmol; 94% yield). Enantioselectivity of **30** and **31** were determined by GC analysis (Cyclosil-B column, 130 °C isothermal: τ_{minor} = 46.0 min, τ_{major} = 50.1 min for **30**; τ_{major} = 49.3 min, τ_{minor} = 55.1 min for **31**) and found to be 91% *ee* for **30** and >99% *ee* for **31**. See Supporting Information: Part B for GC chromatograms.

(**30**): **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.46 (dd, *J* = 5.5, 3.3 Hz; 1H), 6.06 (dd, *J* = 5.5, 3.0 Hz; 1H), 5.40 (t, *J* = 3.8 Hz; 1H), 5.04 (septet, *J* = 6.0 Hz; 1H), 3.59 (br m; 1H), 3.19 (br m; 1H), 2.98 (t, *J* = 3.0 Hz; 1H), 1.68-1.70 (m; 1H), 1.58-1.61 (m; 1H), 1.24-1.27 (6H).

(**31**): **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.21-6.22 (m; 2H), 4.97 (septet, *J* = 6.0 Hz; 1H), 4.69-4.70 (m; 1H), 3.64 (t, *J* = 3.8 Hz; 1H), 3.47 (br m; 1H), 3.32 (br m; 1H), 1.86-1.88 (m; 1H), 1.68 (m; 1H), 1.20-1.23 (m; 6H).

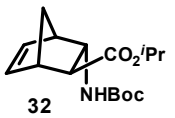
Conversion of **30** *and* **31** *to their corresponding β–amino acid derivatives:*



The mixture of **30** and **31** (250 mg; 1.11 mmol) was placed in a 200 mL round-bottom flask together with 50 mL THF-H_2O mixture (20:1) and the resulting solution was cooled to 0 °C. Aluminum foil, cut into small pieces (600 mg; 22.2 mmol; washed with Et_2O, dipped into 2% aqueous $HgCl_2$ solution and washed again with MeOH and Et_2O), was then added to the solution at 0 °C with vigorous stirring. The resulting mixture was stirred vigorously at 0 – 4 °C for 24 h. The reaction mixture (dark grey suspension) was filtered through a Celite® pad and washed with 1:1 THF-MeOH (100 mL). The filtrate was concentrated in vacuo and the residue was taken in CH_2Cl_2, dried over anh. Na_2SO_4 and concentrated to obtain a pale yellow oil. Purification by silica gel column chromatography (20:1 to 5:1 CH_2Cl_2-MeOH) afforded a colorless oil (206 mg, 1.06 mmol; 95% yield). **^{1}H-NMR (500 MHz, $CDCl_3$):** δ (*major*) 6.39 (dd, *J* = 5.8, 3.3 Hz; 1H), 6.19 (dd, *J* = 5.8, 3.0 Hz; 1H), 5.01 (septet, *J* = 6.3 Hz; 1H), 3.67 (t, *J* = 2.8 Hz; 1H), 2.95 (br m; 1H), 2.83 (br m; 1H), 2.38 (t, *J* = 3.5 Hz; 1H), 1.68-1.70 (m; 1H), 1.55-1.58 (m; 1H), 1.45-1.47 (br m; 2H), 1.22-1.24 (m; 6H); δ (*minor*) 6.15 (dd, *J* = 5.8, 3.3 Hz; 1H), 6.06 (dd, *J* = 5.8, 2.8 Hz; 1H), 4.94 (septet, *J* = 6.0 Hz; 1H), 3.15-3.16 (m; 1H), 3.07 (br m; 1H), 2.55 (br m; 1H), 1.75-1.77 (m; 1H), 1.69-1.70 (m; 1H), 1.45-1.47 (br m; 2H), 1.18-1.20 (m; 6H).

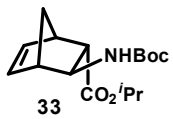
To a solution of this oil (140 mg; 0.72 mmol) and K_2CO_3 (109 mg; 0.79 mmol) in 1:1 MeOH-H_2O (25 mL), was added Boc_2O (173 mg; 0.79 mmol) and the resulting solution was stirred at rt for 3 h. MeOH was then removed in vacuo, the residue was acidified with 5% citric acid solution to pH ~3 and extracted with CH_2Cl_2 (10 mL × 3). Combined extracts was dried over anh. Na_2SO_4 and concentrated in vacuo to obtain a pale yellow oil. Purification by silica gel column chromatography (10:1 to 5:1 hexanes/EtOAc gradient) afforded **32** (126 mg) and **33** (85 mg) as white crystalline solids (0.71 mmol; >99% yield).

(**32**): **Melting point:** 61-62 °C; **FT-IR (thin film):** 3371 (br), 2978 (m), 2918 (w), 1703 (s), 1504 (m), 1455 (w), 1366 (s), 1249 (s), 1164 (s), 1106 (s), 1045 (w), 1024 (w), 942 (w), 861 (w), 729 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.38 (dd, *J* = 5.5, 3.0 Hz; 1H), 6.14 (dd, *J* = 5.5, 2.8 Hz; 1H), 5.01 (septet, *J* = 6.0 Hz; 1H), 4.44 (br s; 1H), 4.25-4.28 (br m; 1H), 2.99 (br s; 1H), 2.93 (s; 1H), 1.77-1.79 (m; 2H), 1.43-1.45 (m; 1H), 1.40 (s; 9H), 1.21-1.23 (m; 6H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 173.6, 155.1, 139.4, 134.1, 79.1, 67.8, 55.3, 53.1, 47.1, 46.2, 46.0, 29.6, 28.2, 21.7; **HRMS (ESI+):** Calcd for $C_{16}H_{25}NO_4Na$ ($[M+Na]^+$):



318.16758, Found: 318.16783; **Optical rotation:** $[\alpha]_D^{23}$ +97.6 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of 91% *ee*.

(**33**): **Melting point:** 79-80 °C; **FT-IR (thin film):** 3370 (br), 2978 (m), 2933 (w), 1713 (s), 1517 (s), 1456 (w), 1366 (m), 1284 (m), 1253 (m), 1170 (s), 1106 (s), 1046 (m), 1027 (w), 979 (w), 907 (w), 882 (w), 748 (w), 716 (m); **^{1}H-NMR (500 MHz, $CDCl_3$):** δ 6.18 (dd, *J* = 5.5, 3.5 Hz; 1H), 6.04 (br m; 1H), 4.94 (septet, *J* = 6.0 Hz; 1H), 4.80 (br s; 1H), 3.78 (br s; 1H), 3.09 (s; 1H), 2.82 (br s; 1H), 2.48 (br s; 1H), 1.55-1.60 (m; 2H), 1.43 (s; 9H), 1.17-1.24 (m; 6H); **^{13}C-NMR (125 MHz, $CDCl_3$):** δ 172.2, 155.1, 136.0, 135.1, 79.2, 67.6, 54.8, 52.9, 48.9, 46.7, 44.8, 29.6, 28.3, 21.7; **HRMS (ESI+):** Calcd for $C_{16}H_{25}NO_4Na$ ($[M+Na]^+$): 318.16758, Found: 318.16736; **Optical rotation:** $[\alpha]_D^{23}$ +76.7 ° (*c* 1.00, $CHCl_3$) for an enantiomerically enriched sample of >99% *ee*.



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