Organocatalytic Enantioselective Formal C(sp^2)−H Alkylation

Madhu Sudan Manna, and Santanu Mukherjee*

Department of Organic Chemistry, Indian Institute of Science, Bangalore 560 012, INDIA

sm@orgchem.iisc.ernet.in

SUPPORTING INFORMATION: PART A

General: Infrared (FT-IR) spectra were recorded on a Perkin Elmer Spectrum BX spectrophotometer, ν_{max} in cm^{-1} and the bands are characterized as broad (br), strong (s), medium (m), and weak (w). NMR spectra were recorded on Bruker Ultrashield spectrometer at 400 MHz (for ^{1}H-NMR) and 100 MHz (for ^{13}C-NMR). Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as internal standard ($CDCl_3$: δ 7.26, CD_3OD: δ 3.31 for ^{1}H-NMR and $CDCl_3$: δ 77.16, CD_3OD: δ 49.00 for ^{13}C-NMR). For ^{1}H-NMR, data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, dd = double doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants (Hz) and integration. High resolution mass spectrometry was performed on Micromass Q-TOF Micro instrument. Optical rotations were measured on JASCO P-2000 polarimeter. Melting points were measured in open glass capillary using ANALAB μ-Thermocal 10 melting point apparatus. Enantiomeric ratios were determined by Shimadzu LC-20AD HPLC instrument and SPD-20A UV/Vis detector using stationary phase chiral columns (25 cm × 0.46 cm) in comparison with authentic racemic compounds.

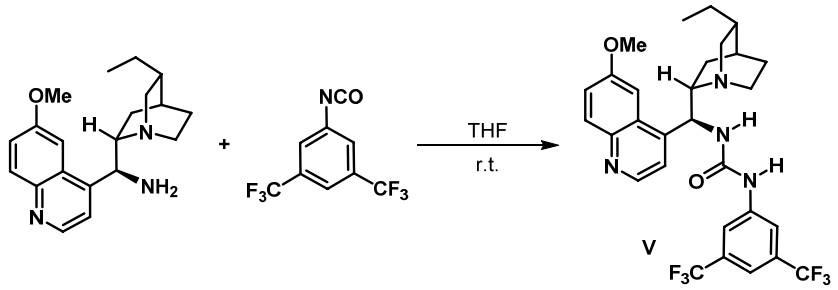
Unless stated otherwise, all reactions were carried out with distilled and dried solvents under an atmosphere of nitrogen or argon, oven (120 °C) dried glassware with standard vacuum-line techniques. Organic solvents used for carrying out reactions were dried using standard methods. All work up and purification were carried out with reagent grade solvents in air. Thin-layer chromatography was performed using Merck silica gel 60 F_{254} pre-coated plates (0.25 mm). Column chromatography was performed using silica gel (230-400 or 100-200 mesh). Catalyst **I-IV** were synthesized according to literature procedure.[1,2,3]

(1) Okino, T.; Hoashi, Y.; Takemoto, Y. *J. Am. Chem. Soc.* **2003**, *125*, 12672.

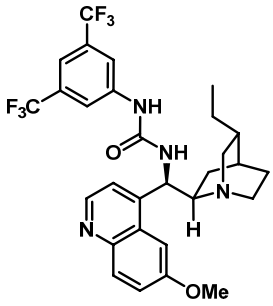
(2) Vakulya, B.; Varga, S.; Csámpai, A.; Soós, T. *Org. Lett.* **2005**, *7*, 1967.

(3) (a) Manna, M. S.; Kumar, V.; Mukherjee, S. *Chem. Commun.* **2012**, *48*, 5193. (b) Manna, M. S.; Mukherjee, S. *Chem.–Eur. J.* **2012**, *18*, 15277. (c) Manna, M. S.; Mukherjee, S. *Chem. Sci.* **2014**, *5*, 1627.

Synthesis of cinchona-derived urea catalysts (V & VII):



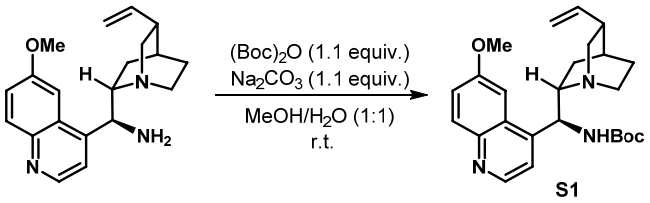
To a solution of 9-amino(9-deoxy)epi-dihydroquinine[3] (1.0 g, 3.072 mmol, 1.0 equiv.) in 10 mL of dry THF in a 50 mL round-bottom flask, was slowly added a solution of 3,5-bis(trifluoromethyl)phenyl isocyanate (0.64 mL, 3.687 mmol, 1.2 equiv.) in 2.0 mL of dry THF at ambient temperature. The mixture was stirred for 16 h under argon atmosphere and the solvent was removed in *vacuo.* The residue was purified by column chromatography on silica gel (230-400 mesh) using CH_2Cl_2/MeOH/Et_3N 100:2:1 as eluent to afford the urea derivative **V** (1.07 g, 1.84 mmol, 60% yield) as an off-white amorphous solid. **m.p.** 138-140 °C; **FT-IR (neat):** 2931 (w), 2864 (w), 1696 (m), 1621 (m), 1569 (m), 1472 (m), 1385 (s), 1274 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.85 (d, *J* = 4.3 Hz, 1H), 8.06 (d, *J* = 9.2 Hz, 1H), 7.78 (s, 1H), 7.64 (s, 2H), 7.43 (dd, *J* = 9.2, 2.3 Hz, 1H), 7.34 (d, *J* = 4.5 Hz, 1H), 7.27 (s, 1H), 6.14 (d, *J* = 6.0 Hz, 1H), 5.67 (br s, 1H), 4.02 (s, 3H), 3.60 (s, 1H), 3.20-3.18 (m, 1H), 2.86-2.81 (m, 1H), 2.68-2.61 (m, 1H), 2.10 (s, 1H), 1.78-1.61 (m, 4H), 1.54-1.48 (m, 1H), 1.37-1.33 (m, 1H), 1.25-1.19 (m, 1H), 1.14-1.08 (m, 1H), 0.91 (dd, *J* = 13.1, 6.2 Hz, 1H), 0.69 (t, *J* = 7.3 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 158.7, 154.6, 147.3, 145.2, 144.2, 140.5, 132.0, 131.9 (q, *J* = 33 Hz), 128.6, 123.1 (q, *J* = 271 Hz), 122.7, 119.1, 118.4, 115.6, 102.0, 77.3, 59.8, 57.3, 55.9, 41.8, 36.7, 28.1, 27.7, 27.2, 24.9, 12.0; **HRMS (ESI+):** Calcd for $C_{29}H_{31}F_6N_4O_2$ ($[M+H]^+$): 581.2351, Found: 581.2350; **Optical rotation:** $[\alpha]_D^{21}$ +30.6 (*c* 1.0, $CHCl_3$).



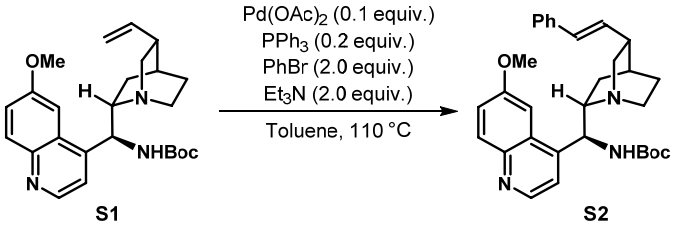
Catalyst VII: Purified by silica-gel (230-400 mesh) column chromatography (CH_2Cl_2/MeOH/Et_3N 100:2:1); Off-white amorphous solid (210 mg, 0.357 mmol, 43% yield); **m.p.** 140-142 °C; **FT-IR (neat):** 2932 (m), 2871 (m), 1621 (m), 1509 (m), 1471 (m), 1381 (s), 1274 (s), 1172 (m), 1127 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.74 (d, *J* = 4.4 Hz, 1H), 8.03 (d, *J* = 9.2 Hz, 1H), 7.77 (s, 2H), 7.68 (s, 1H), 7.41-7.38 (m, 2H), 7.34 (s, 1H), 6.63 (br s, 1H), 5.51 (br s, 1H), 3.98 (s, 3H), 3.46-3.36 (m, 1H), 3.18 (s, 1H), 2.96-2.90 (m, 1H), 2.80-2.72 (m, 2H), 1.60 (s, 1H), 1.48-1.44 (m, 3H), 1.42-1.34 (m, 2H), 1.24-1.22 (m, 1H), 1.11-1.06 (m, 1H), 0.87 (t, *J* = 7.5 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 158.4, 155.0, 147.5, 144.9, 141.1, 139.4, 131.8, 131.7 (q, *J* = 33 Hz), 128.2, 123.2 (q, *J* = 273 Hz), 122.4, 118.1, 115.4, 114.1, 101.6, 77.3, 60.7, 55.7, 49.1, 36.9, 26.6,

26.0, 25.4, 25.2, 22.8, 11.9; **HRMS (ESI+):** Calcd for $C_{29}H_{31}F_6N_4O_2$ ($[M+H]^+$): 581.2351, Found: 581.2354; **Optical rotation:** $[\alpha]_D^{24}$ +89.5 (*c* 1.0, $CHCl_3$) [lit[4] +90.3 (*c* 0.36, $CHCl_3$)].

Synthesis of Catalyst VI:



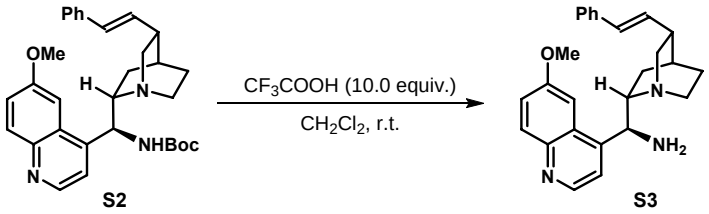
To a solution of 9-amino(9-deoxy)epiquinine[3] (90 mg, 0.773 mmol, 1.0 equiv.) in 6.0 mL of MeOH/H_2O (1:1) was added Na_2CO_3 (186 mg, 0.850 mmol, 1.1 equiv.) followed by $(Boc)_2O$ (186 mg, 0.850 mmol, 1.1 equiv.) and the mixture was stirred at r.t. After 24 h, solvent (MeOH) was removed in *vacuo* and the residue was dissolved in 10 mL of CH_2Cl_2 and 10 mL of H_2O. Organic phase was separated from aqueous phase and the aqueous phase was extracted with CH_2Cl_2 (2 × 10 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain **S1** as a colorless sticky foam (305 mg, 0.720 mmol, 93% yield). **FT-IR (neat):** 2923 (m), 2862 (m), 1619 (m), 1589 (m), 1507 (m), 1225 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.71 (d, *J* = 4.1 Hz, 1H), 8.01 (d, *J* = 9.2 Hz, 1H), 7.62 (s, 1H), 7.37-7.34 (m, 2H), 5.89 (br s, 1H), 5.72-5.64 (m, 1H), 4.96-4.90 (m, 2H), 3.95 (s, 3H), 3.24 (dd, *J* = 13.6, 10.2 Hz, 1H), 3.14 (s, 1H), 2.98 (s, 1H), 2.79-2.72 (m, 1H), 2.70-2.64 (m, 1H), 2.64-2.19 (m, 2H), 1.63-1.57 (m, 3H), 1.33 (s, 9H), 0.93 (dd, *J* = 13.2 Hz, 6.4 Hz, 1H), 0.78-0.75 (m, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 157.6, 155.4, 147.5, 144.7, 141.2, 141.2, 131.7, 131.7, 128.4, 121.4, 114.4, 101.8, 79.5, 77.2, 55.9, 55.5, 40.8, 39.5, 28.2, 28.1, 27.9, 27.3, 25.9.



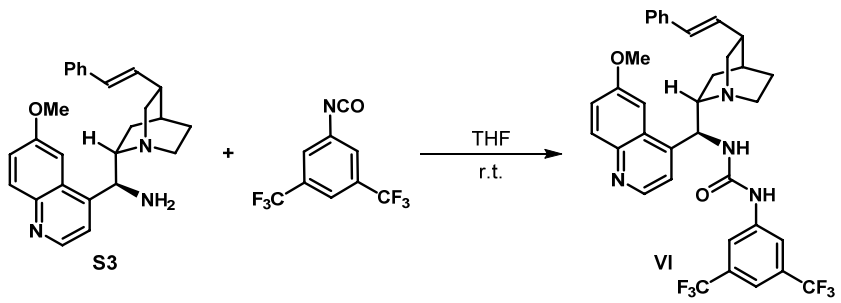
In an oven-dried round-bottom flask, cooled under air, was taken **S1** (280 mg, 0.661 mmol, 1.0 equiv.) with 2.6 mL of absolute toluene. To this was added $Pd(OAc)_2$ (15 mg, 0.066 mmol, 0.1 equiv.), PPh_3 (35 mg, 0.132 mmol, 0.2 equiv.) and bromobenzene (0.14 mL, 1.32 mmol, 2.0 equiv.), followed by Et_3N (0.18 mL, 1.32 mmol, 2.0 equiv.). The resulting mixture was stirred at 110 °C. After 72 h, reaction mixture was cooled to r.t., filtered through a plug of cotton, washed with $CHCl_3$ and the filtrate was concentrated in *vacuo*. The crude reaction

(4) McCooey, S. H.; Connon, S. J. *Angew. Chem. Int. Ed.* **2005**, *44*, 6367.

mixture was purified by silica-gel (230-400 mesh) column chromatography (EtOAc to 1% MeOH in EtOAc) to obtain **S2** as an off-white solid (75 mg, 0.150 mmol, 23% yield). **m.p.** 78-79 °C; **FT-IR (neat):** 2929 (m), 2862 (m), 1695 (s), 1620 (m), 1473 (m), 1363 (m), 1241 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.74 (d, *J* = 4.3 Hz, 1H), 8.02 (d, *J* = 9.1 Hz, 1H), 7.68-7.64 (m, 2H), 7.55-7.51 (m, 1H), 7.46-7.43 (m, 2H), 7.38-7.36 (m, 1H), 7.24-7.21 (m, 1H), 7.16-7.15 (m, 1H), 6.33 (d, *J* = 15.8 Hz, 1H), 6.07 (dd, *J* = 15.8, 7.9 Hz, 1H), 3.97 (s, 3H), 3.38-3.32 (m, 1H), 3.24-3.22 (m, 1H), 2.83-2.71 (m, 2H), 2.46 (s, 1H), 1.73-1.62 (m, 3H), 1.34 (s, 9H), 1.27-1.25 (m, 2H), 1.01 (dd, *J* = 13.0, 6.6 Hz, 1H), 0.88-0.85 (m, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 157.8, 155.6, 147.7, 144.8, 137.2, 133.1, 132.9, 132.1, 131.9, 130.3, 128.6, 128.5, 127.2, 126.0, 121.5, 101.9, 79.6, 77.3, 56.7, 55.7, 53.5, 40.8, 39.2, 28.2, 27.9, 27.8, 26.1; **HRMS (ESI+):** Calcd for $C_{31}H_{38}N_3O_3$ ($[M+H]^+$): 500.2913, Found: 500.2916.

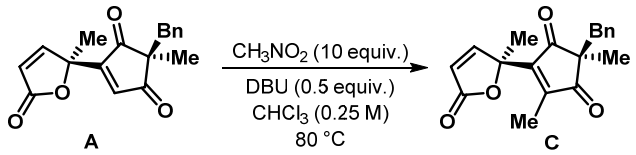


In an oven-dried round-bottom flask, **S2** (75 mg, 0.150 mmol, 1.0 equiv.) was taken with 0.6 mL of absolute CH_2Cl_2. To this was added trifluoroacetic acid (0.12 mL, 1.5 mmol, 10.0 equiv.) and the resulting solution was stirred at r.t. After 2 h, reaction mixture was cooled to 0 °C and carefully quenched with 20% aqueous Na_2CO_3 solution. Reaction mixture was diluted with 5 mL of $CHCl_3$ and the organic phase was separated from aqueous phase. Aqueous phase was washed with additional $CHCl_3$ (2 × 10 mL), combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The residue was dissolved in 10 mL 1.0 M aq. HCl and 10 mL CH_2Cl_2, organic phase was separated and discarded. The aqueous phase was made alkaline with aq. ammonia solution and the product was extracted with $CHCl_3$ (3 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated to obtain **S3** as a colorless oil (39 mg, 0.097 mmol, 65% yield). **FT-IR (neat):** 2930 (m), 1621 (m), 1509 (m), 1471 (m), 1381 (m), 1214 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.76 (d, *J* = 4.4 Hz, 1H), 8.04 (d, *J* = 9.1 Hz, 1H), 7.49 (s, 1H), 7.40-7.37 (m, 1H), 7.30-7.24 (m, 5H), 7.21-7.16 (m, 1H), 6.36 (d, *J* = 15.8 Hz, 1H), 6.18 (dd, *J* = 15.8, 7.9 Hz, 1H), 4.63 (d, *J* = 7.5 Hz, 1H) 3.96 (s, 3H), 3.40-3.34 (m, 1H), 3.28-3.22 (m, 1H), 3.16-3.15 (m, 1H), 2.87-2.80 (m, 2H), 2.46 (s, 1H), 2.12 (br s, 2H), 1.70-1.69 (m, 1H), 1.61-1.58 (m, 2H), 1.54-1.49 (m, 1H), 0.83 (dd, *J* = 13.5, 7.2 Hz, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 157.6, 147.8, 146.9, 144.7, 137.3, 135.5, 131.8, 129.9, 128.7, 128.4, 128.1, 127.0, 125.9, 121.1, 102.0, 77.2, 57.0, 55.5, 40.9, 39.4, 29.6, 28.2, 27.9, 26.1; **HRMS (ESI+):** Calcd for $C_{26}H_{30}N_3O$ ($[M+H]^+$): 400.2389, Found: 400.2388.



In an oven-dried round-bottom flask, **S3** (36 mg, 0.090 mmol, 1.0 equiv.) was taken with 0.15 mL of absolute THF under argon atmosphere. To this was added a solution of 3,5-bis(trifluoromethyl)phenyl isocyanate (28 mg, 0.108 mmol, 1.2 equiv.) in 0.2 mL absolute THF and the resulting mixture was stirred at r.t. After 20 h, solvent was removed under reduced pressure and the residue was purified by silica-gel (230-400 mesh) column chromatography using CH_2Cl_2/MeOH/Et_3N 100:2:1 as eluent to obtain **VI** as a white foam (30 mg, 0.045 mmol, 51% yield). **m.p.** 130-132 °C; **FT-IR (neat):** 2922 (m), 2853 (w), 1697 (m), 1570 (m), 1472 (m), 1385 (s), 1274 (s); **^{1}H-NMR (400 MHz, CD_3OD):** δ 8.70 (d, *J* = 4.5 Hz, 1H), 7.97-7.95 (m, 3H), 7.86 (s, 1H), 7.62 (d, *J* = 4.5 Hz, 1H), 7.46-7.44 (m, 2H), 7.37-7.35 (m, 2H), 7.28-7.24 (m, 2H), 7.19-7.15 (m, 1H), 6.46 (d, *J* = 15.8 Hz, 1H), 6.36 (dd, *J* = 15.8, 7.7 Hz, 1H), 5.70 (br s, 1H), 4.62 (s, 1H) 4.01 (s, 3H), 3.63-3.57 (m, 1H), 3.48-3.42 (m, 1H), 2.95-2.89 (m, 2H), 2.61 (s, 1H), 1.80-1.74 (m, 3H), 1.37-1.33 (m, 1H), 1.03-0.94 (m, 1H), 0.91-0.88 (m, 1H); **^{13}C-NMR (100 MHz, CD_3OD):** δ 159.8, 156.6, 148.2, 147.3, 147.3, 145.1, 143.2, 140.1, 138.7, 133.7, 133.0 (q, *J* = 33 Hz), 131.7, 131.4, 130.0, 129.4, 128.1, 127.1, 124.7 (q, *J* = 273 Hz), 123.6, 119.0, 103.1, 60.7, 57.4, 56.3, 42.1, 40.2, 30.7, 30.0, 28.3, 27.5; **HRMS (ESI+):** Calcd for $C_{35}H_{33}F_6N_4O_2$ ($[M+H]^+$): 655.2508, Found: 655.2510; **Optical rotation:** $[\alpha]_D^{23}$ +16.2 (*c* 1.0, $CHCl_3$).

The initial breakthrough towards C(sp²)–H methylation:

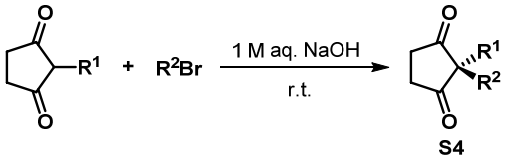


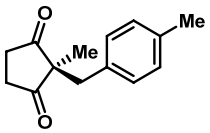
In an oven and vacuum-dried round-bottom flask, **A**[3c] (50 mg, 0.168 mmol, 1.0 equiv.) was taken with 0.7 mL of freshly distilled $CHCl_3$ under argon atmosphere. To this was added nitromethane (90 µL, 1.68 mmol, 10 equiv.) followed by DBU (13 µL, 0.084 mmol, 0.5 equiv.) and the resulting mixture was refluxed at 80 °C. After 36 h reaction mixture was cooled to r.t., solvent was removed under *vacuo* and the residue was purified by silica-gel column chromatography (10% EtOAc in petroleum ether) to obtain **C** a light yellow oil as 1:1 mixture of two atropisomers (25 mg, 0.080 mmol, 48 % yield); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 8.01 (d, *J* = 5.6 Hz, 1H), 7.74 (d, *J* = 5.6 Hz, 1H), 7.15-7.14 (m, 3H), 7.06-7.04 (m, 3H), 6.87-6.85 (m, 2H),

6.74-6.72 (m, 2H), 6.00 (d, *J* = 5.6 Hz, 1H), 5.84 (d, *J* = 5.6 Hz, 1H), 3.02 (d, *J* = 13.0 Hz, 1H), 2.97 (d, *J* = 13.0 Hz, 1H), 2.91 (d, *J* = 13.0 Hz, 1H), 2.87 (d, *J* = 13.0 Hz, 1H), 2.01 (s, 3H), 1.98 (s, 3H), 1.62 (s, 3H), 1.24 (s, 3H), 1.20 (s, 3H), 1.17 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 206.0, 205.8, 204.9, 204.8, 171.1, 171.0, 157.5, 157.4, 156.0, 153.2, 135.6, 135.5, 129.6, 129.2, 128.5, 127.3, 120.2, 119.8, 86.9, 86.7, 52.3, 52.0, 42.3, 42.1, 24.5, 24.3, 19.0, 18.6, 10.1, 10.1; **HRMS (ESI+):** Calcd for $C_{19}H_{18}O_4Na$ ($[M+Na]^+$): 333.1103, Found: 333.1100.

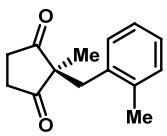
Preparation of 2,2-disubstituted cyclopentane-1,3-dione (S4):

2,2-Disubstituted cyclopentane-1,3-diones were synthesized following our previously reported procedure.[3c]





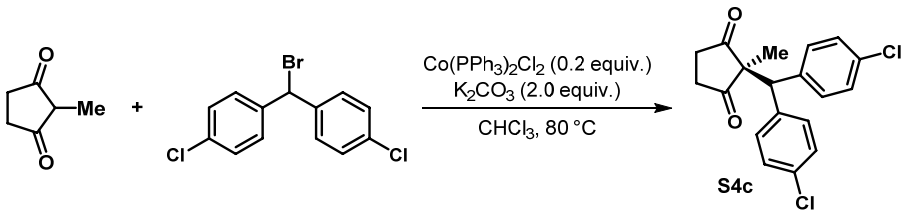
Compound S4a: 2-Methyl cyclopentane-1,3-dione (500 mg, 4.46 mmol, 1.0 equiv.) was taken with 5.0 mL of 1.0 M aq. NaOH solution and the suspension was stirred at r.t. for 10 min. To this mixture was added 4-methyl-benzyl bromide (1.65 g, 8.91 mmol, 2.0 equiv.) at once and the resulting biphasic solution was stirred vigorously at r.t. After being stirred for 48 h, the reaction mixture was diluted with 10 mL of EtOAc, organic phase was separated from aqueous phase and the aqueous phase was back-extracted with EtOAc (2 × 10 mL). The combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel column chromatography (8-10% EtOAc in petroleum ether) to obtain a colorless oil (750 mg, 3.46 mmol, 77% yield); **FT-IR (Thin film):** 2971 (w), 2925 (w), 1764 (w), 1718 (s), 1449 (m), 1415 (w), 1370 (w), 1323 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.01 (d, *J* = 7.6 Hz, 2H), 6.90 (d, *J* = 7.6 Hz, 2H), 2.90 (s, 2H), 2.59-2.45 (m, 2H), 2.26 (s, 3H), 2.13-1.99 (m, 2H), 1.17 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 217.7, 136.9, 132.7, 129.5, 129.3, 58.4, 42.9, 35.9, 21.1, 19.9.



Compound S4b: Purified by silica-gel column chromatography (8-10% EtOAc in petroleum ether); Colorless oil (625 mg, 2.89 mmol, 65% yield); **FT-IR (Thin film):** 2975 (m), 2929 (m), 2860 (w), 1762 (m), 1718 (s), 1489 (m), 1448 (m), 1410 (m), 1371 (m), 1324 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.09-7.02 (m, 3H), 6.95 (d, *J* = 7.4 Hz, 1H), 3.01 (s, 2H), 2.59-2.45 (m, 2H), 2.24 (s, 3H), 2.15-2.05 (m, 2H), 1.20 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 217.8, 136.8, 134.3, 131.0, 129.7, 127.4, 126.0, 58.1, 39.9, 36.0, 19.9, 19.7.

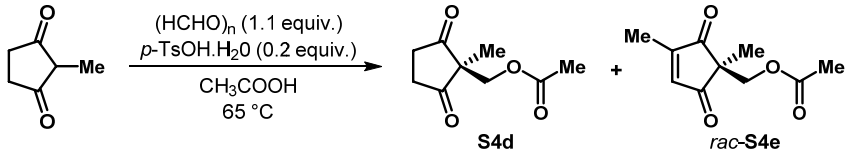
Preparation of 2-(4,4-dichlorobenzhydryl)-2-methylcyclopentane-1,3-dione (S4c):

2-(4,4-Dichlorobenzhydryl)-2-methylcyclopentane-1,3-dione was synthesized according to our previously reported procedure.[3c]



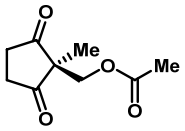
In an oven and vacuum-dried round-bottom flask, equipped with reflux condenser, K_2CO_3 (1.23 g, 8.91 mmol, 2.0 equiv.) was taken and heated at 180 °C under vacuum for 3 h, cooled to r.t. and purged with argon. To this was added 2-methyl-cyclopentane-1,3-dione (500 mg, 4.46 mmol, 1.0 equiv.), 4,4′-dichlorobenzhydryl bromide (2.11 g, 6.68 mmol, 1.5 equiv.), $Co(PPh_3)_2Cl_2$ (584 mg, 0.892 mmol, 0.20 equiv.) followed by 21.0 mL of dry $CHCl_3$ and the resulting solution was stirred at 80 °C under argon. After being stirred for 48 h, reaction mixture was cooled to r.t., quenched with 20 mL of distilled water and diluted with 20 mL of CH_2Cl_2. Organic phase was separated from aqueous phase, aqueous phase was extracted with CH_2Cl_2 (2 × 10 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel column chromatography (10-15% EtOAc in petroleum ether) to obtain a colorless thick oil (540 mg, 1.55 mmol, 35% yield). **FT-IR (Thin film):** 2970 (m), 2920 (m), 1720 (s), 1598 (w), 1496 (m), 1451 (m), 1416 (m), 1254 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.33 (d, *J* = 8.4 Hz, 4H), 7.22 (d, *J* = 8.4 Hz, 4H), 4.35 (s, 1H), 2.71-2.57 (m, 2H), 2.22-2.07 (m, 2H), 1.07 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 216.8, 137.8, 133.3, 131.0, 128.8, 60.1, 56.1, 35.7, 20.6.

Preparation of (1-methyl-2,5-dioxocyclopentyl)methyl acetate (S4d):

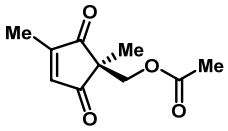


In an oven and vacuum-dried round-bottom flask, 2-methyl-cyclopentane-1,3-dione (500 mg, 4.46 mmol, 1.0 equiv.), paraformaldehyde (147 mg, 4.90 mmol, 1.1 equiv.) and *p*-toluenesulfonic acid monohydrate (170 mg, 0.89 mmol, 0.2 equiv.) was taken with 22 mL of acetic acid and the resulting suspension was stirred at 65 °C. After 72 h, reaction mixture was cooled to r.t., solvent was removed under vacuum and the residue was dissolved in 20 mL $CHCl_3$ and 20 mL H_2O. Organic phase was separated from aqueous phase and the aqueous phase was washed with additional $CHCl_3$ (2 × 10 mL). Combined organic phase was washed with sat.

$NaHCO_3$ solution (2 × 20 mL), dried over anh. Na_2SO_4 and concentrated. The crude mixture was purified by silica-gel column chromatography (5-20% EtOAc in petroleum ether) to obtain (1-methyl-2,5-dioxocyclopentyl)methyl acetate **S4d** (330 mg, 1.79 mmol, 40% yield) and *rac*-(1,3-dimethyl-2,5-dioxocyclopent-3-en-1-yl)methyl acetate *rac*-**S4e** (438 mg, 2.23 mmol, 50% yield).



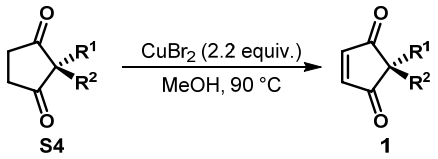
Compound S4d: Purified by silica-gel column chromatography (15-20% EtOAc in petroleum ether); Light yellow oil (330 mg, 1.79 mmol, 40% yield); **FT-IR (Thin film):** 2973 (m), 2930 (m), 1734 (m), 1699 (s), 1490 (w), 1327 (m), 1259 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 4.15 (s, 2H), 2.87-2.73 (m, 4H), 1.94 (s, 3H), 1.09 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 214.3, 169.9, 66.6, 54.9, 35.7, 20.6, 16.4.

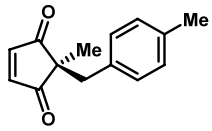


Compound *rac*-S4e: Purified by silica-gel column chromatography (5-7% EtOAc in petroleum ether); Yellow oil (438 mg, 2.23 mmol, 50% yield); **FT-IR (Thin film):** 2932 (m), 1738 (m), 1666 (s), 1490 (w), 1250 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.01 (s, 1H), 4.19 (d, J = 10.9 Hz, 1H), 4.15 (d, J = 10.9 Hz, 1H), 2.13 (s, 3H), 1.88 (s, 3H), 1.11 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 204.9, 203.3, 169.7, 160.7, 144.3, 64.7, 49.4, 20.2, 15.5, 11.3.

Preparation of 2,2-disubstituted cyclopentene-1,3-dione (1):

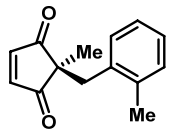
2,2-Disubstituted cyclopentene-1,3-diones (**1a**, **1b**, **1e-1m**, **1o**, **1p**, **1r**) were synthesized according to our previously reported procedure.[3c] Same procedure was followed to synthesize other substrates.



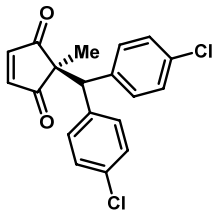


Compound 1c: To a solution of 2-methyl-2-(4-methylbenzyl)cyclopent-4-ene-1,3-dione (725 mg, 3.352 mmol, 1.0 equiv.) in 20 mL of MeOH was added copper(II) bromide (1.65 g, 7.37 mmol, 2.2 equiv.) and the resulting brown solution was stirred at 90 °C under argon atmosphere. After 1 h the reaction mixture was cooled to r.t., quenched with 10 mL of distilled water followed by 10 mL of 1.0 M aq. HCl solution, 20 mL of CH_2Cl_2 was added and the organic phase was separated from aqueous phase. Aqueous phase was washed with additional CH_2Cl_2 (2 × 20 mL), combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel column chromatography (2-5% EtOAc in petroleum ether) to obtain a yellow crystalline solid (625 mg, 2.91 mmol, 87% yield); **m.p.** 113-114 °C; **FT-IR (Thin film):** 2927 (m), 1743 (m), 1698 (s), 1449 (m), 1372 (m), 1325 (m), 1257 (m); **^{1}H-**

NMR (400 MHz, $CDCl_3$): δ 6.98 (s, 2H), 6.94 (d, *J* = 7.7 Hz, 2H), 6.79 (d, *J* = 7.7 Hz, 2H), 2.94 (s, 2H), 2.22 (s, 3H), 1.23 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.5, 148.8, 136.6, 132.5, 129.6, 129.1, 52.6, 40.6, 21.1, 19.3.



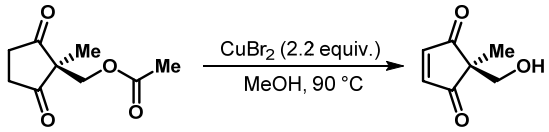
Compound 1d: Purified by silica-gel column chromatography (3-5% EtOAc in petroleum ether); Yellow solid (820 mg, 3.82 mmol, 76% yield); **m.p.** 103-104 °C; **FT-IR (Thin film):** 2930 (m), 1743 (m), 1703 (s), 1453 (m), 1326 (m), 1245 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.03-6.95 (m, 5H), 6.83 (d, *J* = 7.5 Hz, 1H), 3.05 (s, 2H), 2.23 (s, 3H), 1.26 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.5, 148.9, 136.6, 134.1, 131.1, 130.1, 127.1, 125.8, 52.4, 37.3, 19.6, 19.5.



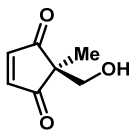
Compound 1q: Purified by silica-gel column chromatography (5% EtOAc in petroleum ether); Yellow crystalline solid (360 mg, 1.04 mmol, 69% yield); **m.p.** 142-143 °C; **FT-IR (Thin film):** 2928 (m), 1741 (m), 1700 (s), 1466 (m), 1255 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.32 (d, *J* = 8.5 Hz, 4H), 7.21 (d, *J* = 8.5 Hz, 4H), 7.04 (s, 2H), 4.34 (s, 1H), 1.15 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.1, 148.8, 137.6, 133.3, 131.0, 128.9, 55.6, 54.9, 19.1.

Preparation of 2-(hydroxymethyl)-2-methylcyclopent-4-ene-1,3-dione (S5):

The above mentioned procedure was followed for the oxidation and in-situ acetyl deprotection of (1-methyl-2,5-dioxocyclopentyl)methyl acetate (**S4d**).

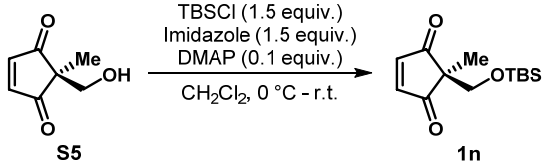


S4d **S5**



Compound S5: Purified by silica-gel column chromatography (10-15% EtOAc in petroleum ether); Yellow oil (75 mg, 0.53 mmol, 33% yield); **FT-IR (Thin film):** 2973 (m), 2930 (m), 1734 (m), 1699 (s), 1490 (w), 1327 (m), 1259 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.32 (s, 2H), 3.80 (d, *J* = 3.6 Hz, 2H), 2.04 (br s, 1H), 1.06 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 206.9, 149.5, 64.7, 52.6, 15.0.

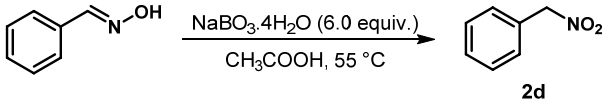
Preparation of 2-(((tert-butyldimethylsilyl)oxy)methyl)-2-methylcyclopent-4-ene-1,3-dione (1n):



In an oven-dried round-bottom flask, **S5** (50 mg, 0.356 mmol, 1.0 equiv.) was taken with 1.7 mL of absolute dichloromethane under Argon and cooled to 0 °C. To this was added *tert*-butyl-dimethylsilyl chloride (81 mg, 0.535 mmol, 1.5 equiv.) and imidazole (36 mg, 0.535 mmol, 1.5 equiv.) followed by DMAP (4.3 mg, 0.035 mmol, 0.1 equiv.) and the resulting solution was slowly warmed to r.t. and stirred for 40 h. Reaction mixture was diluted with 10 mL CH_2Cl_2 and 10 mL of H_2O, organic phase was separated from aqueous phase, aqueous phase was washed with additional CH_2Cl_2 (2 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated. The crude reaction mixture was purified by silica-gel flash column chromatography (2-4% EtOAc in petroleum ether) to obtain **1n** as a yellow oil (71 mg, 0.254 mmol, 78% yield). **FT-IR (Thin film):** 2932 (m), 1734 (m), 1709 (s), 1465 (m), 1258 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.30 (s, 2H), 3.76 (s, 2H), 0.99 (s, 3H), 0.73 (s, 9H), –0.06 (s, 6H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.1, 149.6, 65.9, 52.8, 25.7, 18.1, 14.0, –5.8.

Preparation of Nitroalkanes:

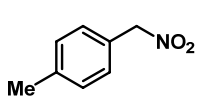
Nitomethane (**2a**) and nitroethane (**2b**) were purchased from commercial source and used as received without any further purification. Nitroalkane **2d** and **2e** were prepared by oxidation of the corresponding oximes.



In an oven-dried round-bottom flask, oxime[5] (500 mg, 4.12 mmol, 1.0 equiv.) was taken with 25 mL of acetic acid. To this solution was added sodium perborate tetrahydrate (3.8 g, 24.76, 6.0 equiv.) and the resulting suspension was stirred at 55 °C. After 20 h, reaction mixture was cooled to r.t. and solvent was removed under vacuum. The residue was added to 20 mL of Et_2O and 20 mL of H_2O, organic phase was separated from aqueous phase and the aqueous phase was back-extracted with Et_2O (2 × 10 mL). Combined organic phase was washed with sat. $NaHCO_3$ solution, dried over anh. Na_2SO_4 and concentrated. The crude mixture was purified by silica-gel column chromatography (5-7% CH_2Cl_2 in petroleum ether) to obtain **2d** as a colorless oil (220 mg, 1.60 mmol, 38%). **FT-IR (Thin film):** 2927 (m), 1700 (m), 1552 (s), 1455 (m),

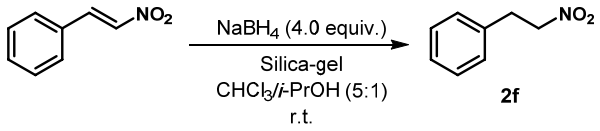
(5) Yang, S. H.; Chang, S. *Org. Lett.* **2001**, *3*, 4209.

1379 (m), 1255 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.48-7.40 (m, 5H), 5.44 (s, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 130.1, 130.1, 129.8, 129.2, 80.1.

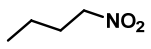


Compound 2e: Purified by silica-gel column chromatography (2-4% EtOAc in petroleum ether); Colorless oil (170 mg, 1.12 mmol, 28% yield); **FT-IR (Thin film):** 2920 (m), 1742 (m), 1552 (s), 1497 (m), 1379 (s), 1222 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.34 (d, *J* = 7.8 Hz, 2H), 7.24 (d, *J* = 7.8 Hz, 2H), 5.40 (s, 2H), 2.38 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 140.2, 130.0, 129.8, 129.9, 79.9, 21.4.

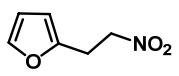
Nitroalkane **2c**, **2f** and **2g** were prepared by reduction of the corresponding nitroalkenes.



In an oven-dried round-bottom flask, nitrostyrene[6] (1.0 g, 6.70 mmol, 1.0 equiv.) was taken with 90 mL $CHCl_3$/*i*-PrOH (5:1) under argon atmosphere. To this was added 10.0 g of silica-gel followed by portion-wise addition of $NaBH_4$ (1.01 g, 26.82 mmol, 4.0 equiv.) over 30 min at r.t. After 2 h, reaction mixture was carefully quenched with 1.0 M aq. HCl solution, filtered through a plug of cotton and the filtrate was washed with 1.0 M aq. HCl (20 ml) and H_2O (25 mL). The organic phase was dried over anh. Na_2SO_4 and concentrated. The crude mixture was purified by silica-gel column chromatography (2% EtOAc in petroleum ether) to obtain **2f** a colorless oil (702 mg, 4.64 mmol, 69% yield). **FT-IR (Thin film):** 2973 (m), 1698 (s), 1552 (s), 1431 (m), 1379 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.31-7.22 (m, 3H), 7.18-7.16 (m, 2H), 4.54 (t, *J* = 7.4 Hz, 2H), 3.26 (t, *J* = 7.4 Hz, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 135.7, 128.9, 128.5, 127.3, 76.2, 33.3.



Compound 2c: Purified by silica-gel column chromatography (5% EtOAc in petroleum ether); Light yellow oil (301 mg, 2.91 mmol, 59% yield); **FT-IR (Thin film):** 2930 (m), 1707 (m), 1561 (s), 1438 (m), 1378 (s), 1255 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 4.38 (t, *J* = 7.0 Hz, 2H), 2.02-1.95 (m, 2H), 1.46-1.37 (m, 2H), 0.96 (t, *J* = 7.4 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 75.6, 29.4, 19.6, 13.4.

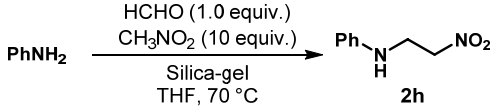


Compound 2g: Purified by silica-gel column chromatography (5% EtOAc in petroleum ether); Colorless oil (340 mg, 2.40 mmol, 67% yield); **FT-IR (Thin**

(6) Mampreian, D. M.; Hoveyda, A. H. *Org. Lett.* **2004**, *6*, 2829.

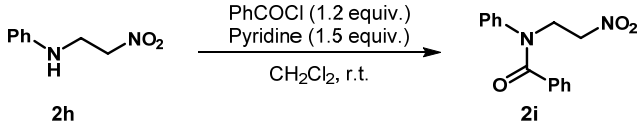
film): 2926 (m), 1705 (m), 1557 (s), 1430 (m), 1378 (m), 1255 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.33 (s, 1H), 6.30 (br s, 1H), 6.13 (d, *J* = 2.7 Hz, 1H), 4.63 (t, *J* = 7.0 Hz, 2H), 3.35 (t, *J* = 7.0 Hz, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 149.4, 142.3, 110.6, 107.5, 73.4, 26.1.

Preparation of *N*-(2-nitroethyl)aniline (2h):



In an oven-dried round-bottom flask, equipped with reflux-condenser, aniline (1.0 g, 10.73 mmol, 1.0 equiv.) was taken with 11.0 mL of absolute THF and the mixture was cooled to 0 °C under argon. To this was added paraformaldehyde (322 mg, 10.73 mmol, 1.0 equiv.) and the suspension was stirred at 0 °C. After 1 h, nitromethane (5.8 mL, 107.3 mmol, 10.0 equiv.) and 1.0 g silica-gel was added and the resulting slurry was heated at 70 °C for 48 h. Reaction mixture was cooled to r.t., filtered through a plug of cotton and the filtrate was concentrated under vacuum. The crude reaction mixture was purified by silica-gel column chromatography (3-5% EtOAc in petroleum ether) to obtain **2h** as a thick yellow oil (950 mg, 5.71 mmol, 53% yield). **FT-IR (Thin film):** 2925 (w), 1603 (s), 1552 (s), 1508 (s), 1385 (m), 1359 (m), 1258 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.24-7.20 (m, 2H), 6.82-6.78 (m, 1H), 6.64-6.62 (m, 2H), 4.57 (t, *J* = 5.4 Hz, 2H), 4.08 (br s, 1H), 3.80 (t, *J* = 5.4 Hz, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 146.2, 129.6, 118.7, 113.1, 74.3, 41.2.

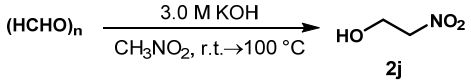
Preparation of *N*-(2-nitroethyl)-*N*-phenylbenzamide (2i):



In an oven-dried round-bottom flask, **2h** (250 mg, 1.50 mmol, 1.0 equiv.) was taken with 3.0 mL of absolute CH_2Cl_2 under argon and cooled to 0 °C. To this was added pyridine (0.18 mL, 2.25 mmol, 1.5 equiv.) followed by benzoyl chloride (0.21 mL, 1.8 mmol, 1.2 equiv.) and the mixture was gently warmed to r.t. and stirred. After 24 h, reaction mixture was quenched with 5 mL of H_2O and diluted with 10 mL of CH_2Cl_2. Organic phase was separated from aqueous phase, aqueous phase was washed with CH_2Cl_2 (2 × 5 mL). The combined reaction mixture was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude mixture was purified by silica-gel column chromatography (10-15% EtOAc in petroleum ether) to obtain **2i** as a light yellow oil (180 mg, 0.665 mmol, 44% yield). **FT-IR (Thin film):** 2959 (w), 1651 (s), 1595 (s), 1552 (s), 1493 (m), 1384 (s), 1306 (m), 1250 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.28-7.13 (m, 8H), 7.10-6.99 (m, 2H), 4.74 (t, *J* = 5.4 Hz, 2H), 4.47 (t, *J* = 5.4 Hz,

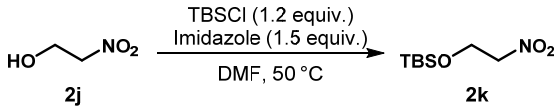
2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 171.1, 142.8, 134.8, 130.2, 130.0, 129.5, 128.8, 128.4, 127.8, 127.5, 127.4, 72.8, 48.3.

Preparation of 2-nitroethan-1-ol (2j):



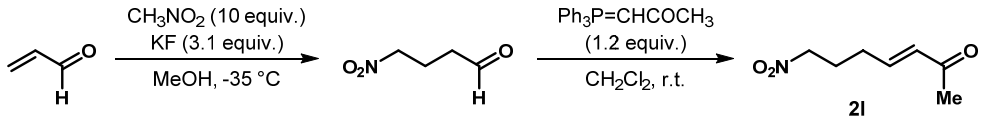
In an oven-dried round-bottom flask, equipped with reflux condenser, paraformaldehyde (500 mg, 16.65 mmol, 1.0 equiv.) was taken with 75.0 mL of nitromethane. To this was added 0.15 mL 3.0 M methanolic KOH solution and the mixture was stirred at r.t. for 2 h and then refluxed at 100 °C for additional 30 min. After cooling the reaction mixture to r.t., solvent was removed under reduced pressure and the residue was purified by silica-gel column chromatography (20-25% EtOAc in petroleum ether) to obtain **2j** as a light yellow oil (910 mg, 1.00 mmol, 60% yield). **FT-IR (Thin film):** 2921 (w), 1637 (m), 1402 (w), 1261 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 4.51 (t, *J* = 4.7 Hz, 2H), 4.12-4.10 (m, 2H), 2.93 (br s, 1H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 77.2, 58.7.

Preparation of *tert*-butyldimethyl(2-nitroethoxy)silane (2k):



In an oven-dried round-bottom flask, **2j** (250 mg, 2.74 mmol, 1.0 equiv.) was taken with 2.7 mL of dry DMF under argon. To this was added imidazole (280 mg, 4.12 mmol, 1.3 equiv.) followed by TBSCl (496 mg, 3.29 mmol, 1.2 equiv.) and the resulting mixture was stirred at 50 °C. After 18 h, reaction mixture was cooled to r.t. and diluted with 5 mL of H_2O and 10 mL of Et_2O. Organic phase was separated from aqueous phase, dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude mixture was purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether) to obtain **2k** as a colorless oil (450 mg, 2.19 mmol, 80% yield). **FT-IR (Thin film):** 2930 (s), 2858 (s), 1701 (m), 1560 (s), 1369 (m), 1257 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 4.45 (t, *J* = 5.0 Hz, 2H), 4.13 (t, *J* = 5.0 Hz, 2H), 0.86 (s, 9H), 0.06 (s, 6H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 77.7, 59.6, 25.7, 18.2, –5.4.

Preparation of *(E)*-7-nitrohept-3-en-2-one (2l):

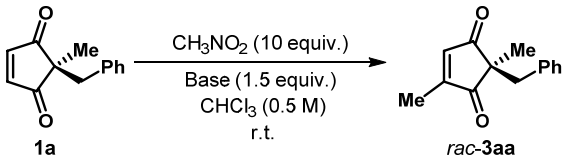


(E)-7-nitrohept-3-en-2-one (**2l**) was prepared according to a modified literature procedure.[7] In an oven and vacuum-dried round-bottom flask, $MeNO_2$ (8.1 mL, 151 mmol, 10 equiv) and KF (2.67 g, 46 mmol, 3.1 equiv) was taken in MeOH (20 mL) under argon and the mixture was cooled to –35 °C. A solution of acrolein (1.0 mL, 15 mmol, 1.0 equiv.) in 5 mL MeOH was added drop wise at –35 °C over 10 minutes. The resulting solution was stirred at –35 °C. After 2 h, the reaction mixture was diluted with 50 mL EtOAc and 50 mL of H_2O. The organic phase was separated, dried over anh. Na_2SO_4 and concentrated in *vacuo* to give the crude 4-nitrobutanal (600 mg, 5.12 mmol, 34% yield). The crude product was used in the next step without further purification or characterization.

To a solution of the crude 4-nitrobutanal (600 mg, 5.12 mmol, 1.0 equiv.) in CH_2Cl_2 (5.1 mL) was added 1-(triphenylphosphoranylidene)-2-propanone (1.95 g, 6.15 mmol, 1.2 equiv) at r. t. The resulting solution was stirred at ambient temperature for 24 h. The reaction mixture was diluted with petroleum ether/EtOAc (1:1) and the solid formed was filtered off, washed with petroleum ether/EtOAc (1:1) and the filtrate was concentrated under reduced pressure. The crude product was purified by silica-gel flash column chromatography (15-20% EtOAc in petroleum ether) to afford **2l** as a colorless oil (195 mg, 1.24 mmol, 24% yield). **FT-IR (Thin film):** 2929 (m), 1698 (s), 1673 (s), 1555 (s), 1434 (s), 1383 (s), 1257 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.72 (dt, *J* = 15.9, 6.7 Hz, 1H), 6.12 (d, *J* = 15.9 Hz, 1H), 4.40 (t, *J* = 6.7 Hz, 2H), 2.36-2.31 (m, 2H), 2.24 (s, 3H), 2.22-2.15 (m, 2H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 198.1, 144.3, 132.5, 74.6, 28.9, 27.3, 25.6.

(7) Jhuo, D.-H.; Hong, B.-C.; Chang, C.-W.; Lee, G.-H. *Org. Lett.* **2014**, *16*, 2724.

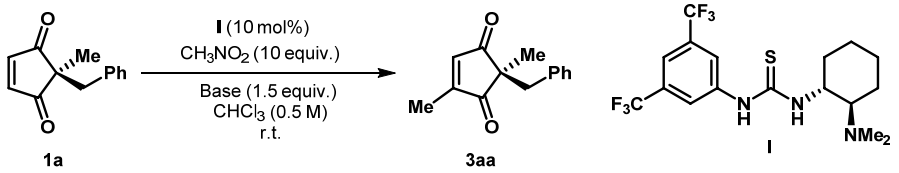
Table 1: Optimization of terminal base: uncatalyzed reaction:



entry	base	time (h)	% conversion of 1a[a]
1	K_2CO_3	12	>95
2	Na_2CO_3	24	<5
3	Li_2CO_3	24	<5
4	$(NH_4)_2CO_3$	24	<5
5	$NaHCO_3$	24	<5
6	2,6-lutidine	24	<5

[a] Conversion of **1a** as determined by ^{1}H-NMR of the crude reaction mixture.

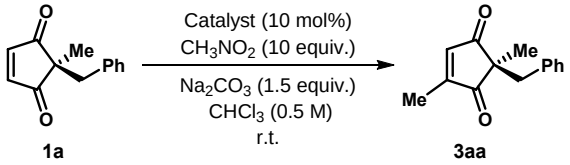
Table 2: Optimization of terminal base: catalytic reaction:



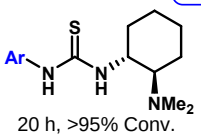
entry	base	time (h)	% conversion of 1a[a]	er
1	none	4	~10	n.d.
2	Na_2CO_3	20	>95	20:80
3	Li_2CO_3	96	20	n.d.
4	$(NH_4)_2CO_3$	27	>95	24:76
5	$NaHCO_3$	72	76	20:80
6	$NaHCO_3$/4Å MS	72	44	20:80
7	2,6-lutidine	72	20	n.d.

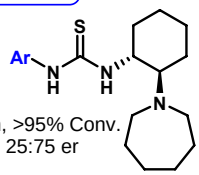
[a] Conversion of **1a** as determined by ^{1}H-NMR of the crude reaction mixture. n.d. = not determined.

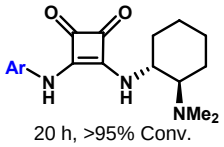
Table 3: Preliminary catalyst screening:

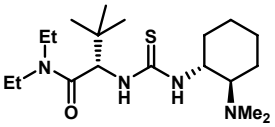


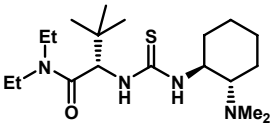
Ar = 3,5-$(CF_3)_2C_6H_3$

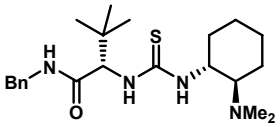

20 h, >95% Conv.
20:80 er

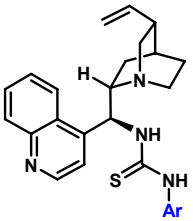

22 h, >95% Conv.
25:75 er

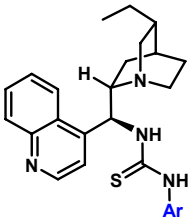

20 h, >95% Conv.
30:70 er

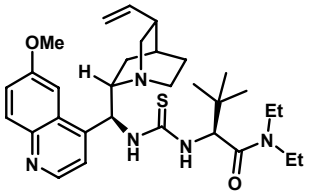

12 h, >95% Conv.
53:47 er

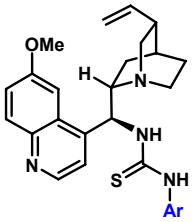

20 h, >95% Conv.
50:50 er

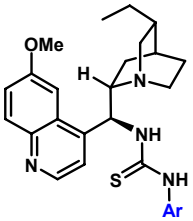

12 h, >95% Conv.
35:65 er

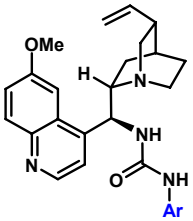

15 h, >95% Conv.
81.5:18.5 er

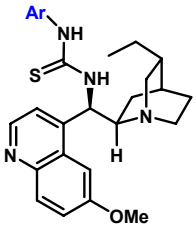

36 h, >95% Conv.
86:14 er

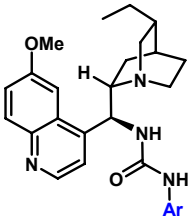

24 h, >95% Conv.
51.5:48.5 er


40 h, >95% Conv.
85:15 er


20 h, >95% Conv.
88:12 er


26 h, >95% Conv.
87.5:12.5 er


26 h, >95% Conv.
13:87 er


–10 °C, $PhCF_3$, 48 h,
>95% Conv., 97:3 er

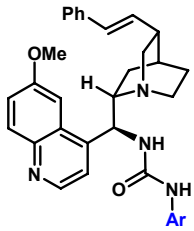
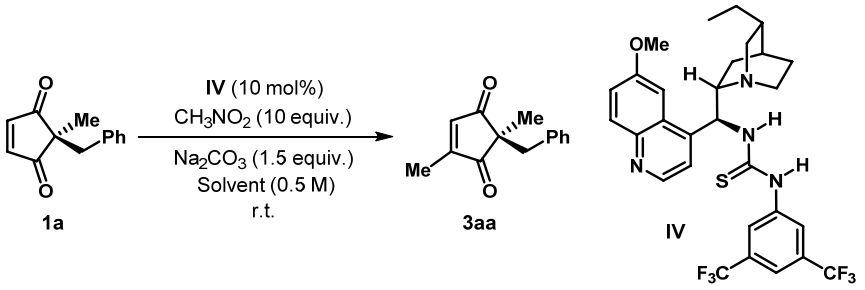
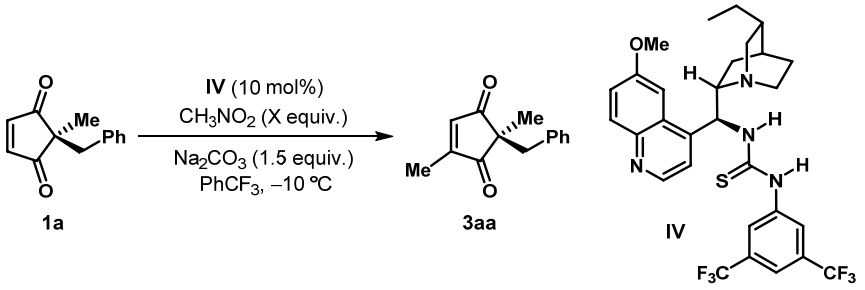

–10 °C, $PhCF_3$, 48 h,
>95% Conv., 94.5:5.5 er

Table 4: Solvent optimization:



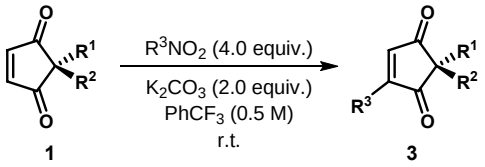
entry	solvent	time (h)	% conversion of 1a	er
1	$CHCl_3$	20	>95	88:12
2	CH_2Cl_2	14	>95	88:12
3	DCE	36	80	87:13
4	$PhCH_3$	12	>95	89:11
5	PhF	20	>95	89:11
6	$PhCF_3$	12	>95	90:10

Table 5: Optimization of concentration and the amount of nitromethane:



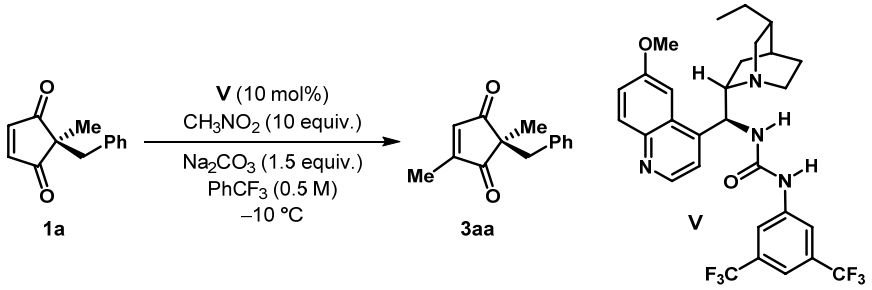
entry	conc. (M)	X	time (h)	% conversion of 1a	er
1	0.5	10	55	>95	95:5
2	1.0	10	50	>95	94:6
3	0.25	10	60	>95	95:5
4	0.5	2	72	62	94.5:5.5
5	0.5	5	72	85	95:5

General procedure for the preparation of racemic products (*rac*-3):



In a glass-vial **1** (0.050 mmol, 1.0 equiv.) and nitroalkane (0.200 mmol, 4.0 equiv.) was taken with 0.1 mL of $PhCF_3$. To this was added K_2CO_3 (0.100 mmol, 2.0 equiv.) the resulting suspension was stirred at r.t. until TLC reveals the complete consumption of **1**. The crude mixture was purified by preparative TLC (Merck silica-gel 60 F_{254} pre-coated plates of 0.25 mm thickness) to obtain the racemic desymmetrized products (*rac*-**3**).

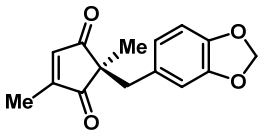
Typical procedure for the organocatalytic enantioselective C(sp²)−H methylation:



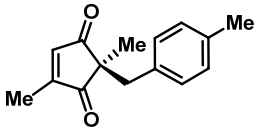
In an oven-dried Schlenk tube Na_2CO_3 (16.0 mg, 0.150 mmol, 1.5 equiv.) was taken and heated to 150 °C under high-vacuum for 15 min, cooled to r.t. under vacuum and purged with argon. Catalyst **V** (5.8 mg, 0.010 mmol, 0.10 equiv.) and 2-benzyl-2-methylcyclopent-4-ene-1,3-dione **1a** (20.0 mg, 0.100 mmol, 1.0 equiv.) was introduced under a positive argon pressure followed by 0.2 mL of absolute $PhCF_3$ and the suspension was cooled to –10 °C. After 10 min nitromethane (54 µL, 1.00 mmol, 10.0 equiv.) was added to it and the resulting mixture was stirred at –10 °C until TLC (3 × 5% EtOAc in petroleum ether) revealed complete conversion of **1a** (48 h). The reaction mixture was diluted with 2 mL of CH_2Cl_2 and 2 mL of distilled water and slowly warmed to r.t. The resulting biphasic solution was transferred to a 50 mL separating funnel, the organic phase was separated from the aqueous phase. Aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). The combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a reddish-brown oil. The crude reaction mixture was purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **3aa** as a crystalline yellow solid (19 mg, 0.088 mmol, 88% yield); **m.p.** 90-91 °C; **FT-IR (Thin film):** 2926 (m), 1736 (s), 1695 (s), 1615 (m),1450 (m), 1373 (m), 1255 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.14-7.12 (m, 3H), 6.91-6.89 (m, 2H), 6.65 (s, 1H), 2.96 (s, 2H), 1.84 (s, 3H), 1.23 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.7, 206.1, 160.9, 144.5, 135.9, 129.6, 128.3, 127.0, 52.7, 41.3, 19.3, 11.1; **HRMS (ESI+):** Calcd. for $C_{14}H_{14}O_2Na$

([M+Na]$^+$): 237.0891, Found: 237.0895; **Optical rotation:** $[\alpha]_D^{21}$ –18.6 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 97:3 er. This product (**3aa**) was recrystallized from petroleum ether/EtOAc (1:1) at 0 °C to obtain light yellow blocks with 99.6:0.4 er. The enantiomeric ratios were determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 7.1 min, τ_{major} = 8.0 min). See Supporting Information: Part B for HPLC chromatograms.

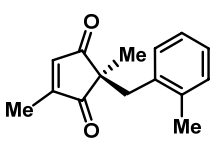
The *ent*-**3aa** was prepared using catalyst **VII**, following the above procedure with 84% yield and 6:94 er. **Optical rotation:** $[\alpha]_D^{21}$ +16.5 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. See Supporting Information: Part B for HPLC chromatograms.



Compound 3ba: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (22 mg, 0.085 mmol, 85% yield); **FT-IR (Thin film):** 2925 (w), 1742 (m), 1698 (s), 1615 (w), 1490 (m), 1373 (w), 1442 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.71 (s, 1H), 6.57 (d, *J* = 7.9 Hz, 1H), 6.38 (s, 1H), 6.36 (d, *J* = 7.9 Hz, 1H), 5.85 (s, 2H), 2.87 (s, 2H), 1.90 (s, 3H), 1.19 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.8, 206.2, 160.9, 147.4, 146.5, 144.5, 129.7, 122.9, 110.1, 108.1, 101.0, 52.7, 40.9, 19.3, 11.3; **HRMS (ESI+):** Calcd. for $C_{15}H_{14}O_4Na$ ([M+Na]$^+$): 281.0790, Found: 281.0790; **Optical rotation:** $[\alpha]_D^{21}$ –21.3 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 96.5:3.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 15.3 min, τ_{major} = 16.6 min). See Supporting Information: Part B for HPLC chromatograms.

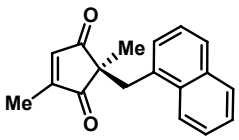


Compound 3ca: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (19 mg, 0.083 mmol, 83% yield); **FT-IR (Thin film):** 2924 (m), 1745 (m), 1700 (s), 1617 (m), 1515 (m), 1374 (m), 1332 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.93 (d, *J* = 7.6 Hz, 2H), 6.77 (d, *J* = 7.6 Hz, 2H), 6.66 (s, 1H), 2.91 (s, 2H), 2.22 (s, 3H), 1.86 (s, 3H), 1.21 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.9, 206.3, 160.9, 144.5, 136.5, 132.8, 129.5, 129.0, 52.7, 40.9, 21.1, 19.3, 11.2; **HRMS (ESI+):** Calcd. for $C_{15}H_{16}O_2Na$ ([M+Na]$^+$): 251.1048, Found: 251.1048; **Optical rotation:** $[\alpha]_D^{21}$ –27.0 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 96.5:3.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.5 min, τ_{major} = 7.9 min). See Supporting Information: Part B for HPLC chromatograms.

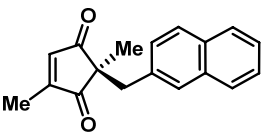


Compound 3da: Purified by silica-gel flash column chromatography (3% EtOAc in petroleum ether); Light yellow oil (18 mg, 0.079 mmol, 79% yield); **FT-IR (Thin film):** 2929 (m), 1717 (s), 1700 (s), 1451 (m), 1374 (w), 1243 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.03-6.99 (m, 2H), 6.98-6.94 (m, 1H),

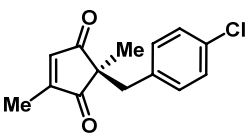
6.81 (d, J = 7.4 Hz, 1H), 6.72 (s, 1H), 3.04 (d, J = 13.6 Hz, 1H), 3.01 (d, J = 13.6 Hz, 1H), 2.22 (s, 3H), 1.88 (s, 3H), 1.25 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.9, 206.3, 161.0, 144.5, 136.6, 134.5, 131.0, 130.1, 127.1, 125.7, 52.6, 37.7, 19.6, 19.4, 11.2; **HRMS (ESI+):** Calcd. for $C_{15}H_{16}O_2Na$ ($[M+Na]^+$): 251.1048, Found: 251.1046; **Optical rotation:** $[\alpha]_D^{25}$ –16.7 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.5 min, τ_{major} = 7.5 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3ea: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Colorless thick oil (22 mg, 0.083 mmol, 83% yield); **FT-IR (Thin film):** 2921 (m), 1783 (s), 1528 (m), 1216 (s); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.98 (d, J = 8.5 Hz, 1H), 7.75 (d, J = 8.0 Hz, 1H), 7.65 (d, J = 8.2 Hz, 1H), 7.50-7.46 (m, 1H), 7.44-7.40 (m, 1H), 7.29-7.26 (m, 1H), 7.11 (d, J = 7.0 Hz, 1H), 6.49 (s, 1H), 3.50 (s, 2H), 1.64 (s, 3H), 1.35 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.8, 206.0, 160.9, 144.2, 133.9, 132.5, 131.6, 128.7, 128.5, 127.9, 126.0, 125.7, 125.1, 124.9, 52.9, 37.8, 19.2, 11.0; **HRMS (ESI+):** Calcd. for $C_{18}H_{16}O_2Na$ ($[M+Na]^+$): 287.1048, Found: 287.1043; **Optical rotation:** $[\alpha]_D^{25}$ –18.5 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 97:3 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 10.1 min, τ_{major} = 12.8 min). See Supporting Information: Part B for HPLC chromatograms.

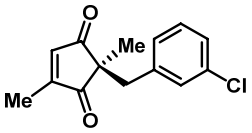


Compound 3fa: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow solid (24 mg, 0.090 mmol, 90% yield); **m.p.** 110-112 °C; **FT-IR (Thin film):** 2927 (m), 1698 (s), 1617 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.74-7.70 (m, 2H), 7.62 (d, J = 8.4 Hz, 1H), 7.42-7.39 (m, 3H), 7.02 (d, J = 8.4 Hz, 1H), 6.61 (s, 1H), 3.13 (s, 2H), 1.79 (s, 3H), 1.29 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.8, 206.1, 160.9, 144.5, 133.6, 133.3, 132.4, 128.4, 128.0, 127.9, 127.8, 127.6, 126.1, 125.8, 52.8, 41.4, 19.5, 11.2; **HRMS (ESI+):** Calcd. for $C_{18}H_{16}O_2Na$ ($[M+Na]^+$): 287.1048, Found: 287.1043; **Optical rotation:** $[\alpha]_D^{21}$ –28.4 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 97:3 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 9.2 min, τ_{major} = 12.4 min). See Supporting Information: Part B for HPLC chromatograms.

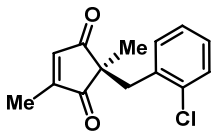


Compound 3ga: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (21 mg, 0.084 mmol, 84% yield); **FT-IR (Thin film):** 2928 (m), 1717 (s), 1700 (s), 1489 (w), 1252

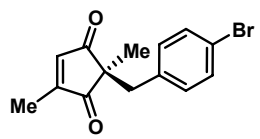
(m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.10 (d, *J* = 8.1 Hz, 2H), 6.84 (d, *J* = 8.1 Hz, 2H), 6.69 (s, 1H), 2.91 (s, 2H), 1.88 (s, 3H), 1.21 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.5, 205.9, 161.0, 144.5, 134.4, 133.0, 131.0, 128.5, 52.5, 40.2, 19.6, 11.2; **HRMS (ESI+):** Calcd. for $C_{14}H_{13}ClO_2Na$ ($[M+Na]^+$): 271.0502, Found: 271.0502; **Optical rotation:** $[\alpha]_D^{21}$ –19.3 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.9 min, τ_{major} = 8.0 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3ha: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (22 mg, 0.088 mmol, 88% yield); **FT-IR (Thin film):** 2928 (m), 1743 (m), 1699 (s), 1453 (m), 1375 (w), 1252 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.11-7.05 (m, 2H), 6.90 (s, 1H), 6.79 (d, *J* = 6.9 Hz, 1H), 6.70 (s, 1H), 2.91 (s, 2H), 1.89 (s, 3H), 1.22 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.3, 205.6, 161.0, 144.5, 137.9, 134.1, 129.7, 129.6, 128.0, 127.3, 52.4, 40.5, 19.5, 11.2; **HRMS (ESI+):** Calcd. for $C_{14}H_{13}ClO_2Na$ ($[M+Na]^+$): 271.0502, Found: 271.0505; **Optical rotation:** $[\alpha]_D^{21}$ –13.3 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 95:5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 7.2 min, τ_{major} = 7.8 min). See Supporting Information: Part B for HPLC chromatograms.

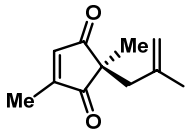


Compound 3ia: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (20 mg, 0.080 mmol, 80% yield); **FT-IR (Thin film):** 2928 (m), 1717 (s), 1700 (s), 1490 (w), 1252 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.28-7.27 (m, 1H), 7.13-7.10 (m, 2H), 7.05-7.03 (m, 1H), 6.80 (s, 1H), 3.13 (s, 2H), 1.97 (s, 3H), 1.25 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 206.7, 205.2, 160.6, 148.4, 143.8, 133.8, 132.1, 129.9, 128.6, 126.6, 51.5, 37.9, 18.5, 11.4; **HRMS (ESI+):** Calcd. for $C_{14}H_{13}ClO_2Na$ ($[M+Na]^+$): 271.0502, Found: 271.0501; **Optical rotation:** $[\alpha]_D^{21}$ –10.2 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 87:13 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 11.7 min, τ_{major} = 13.3 min). See Supporting Information: Part B for HPLC chromatograms.

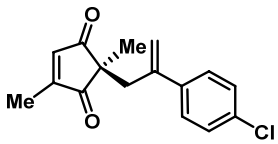


Compound 3ja: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Light yellow oil (24 mg, 0.082 mmol, 82% yield); **FT-IR (Thin film):** 2923 (m), 1743 (m), 1699 (s), 1616 (m), 1488 (m), 1374 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.27 (d, *J* = 7.1 Hz, 2H), 6.79 (d, *J* = 7.1 Hz, 2H), 6.71 (s, 1H), 2.91 (s, 2H), 1.90 (s, 3H), 1.23 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.4, 205.8, 161.0, 144.5, 134.9, 131.4, 131.4, 121.1, 52.4, 40.2, 19.6, 11.2;

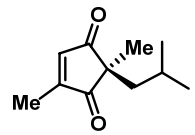
HRMS (ESI+): Calcd. for $C_{14}H_{13}BrO_2Na$ ($[M+Na]^+$): 314.9997, Found: 314.9995; **Optical rotation:** $[\alpha]_D^{21}$ –39.6 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 93.5:6.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 7.4 min, τ_{major} = 8.9 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3ka: Purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); Light yellow oil (15 mg, 0.084 mmol, 84% yield); **FT-IR (Thin film):** 2927 (m), 1710 (s), 1640 (s), 1437 (m), 1248 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.91 (s, 1H), 4.69 (s, 1H), 4.54 (s, 1H), 2.39 (s, 2H), 2.07 (s, 3H), 1.48 (s, 3H), 1.12 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.7, 206.3, 160.6, 144.2, 140.5, 116.0, 51.1, 42.9, 23.9, 19.9, 11.4; **HRMS (ESI+):** Calcd. for $C_{11}H_{15}O_2$ ($[M+H]^+$): 179.1072, Found: 179.1073; **Optical rotation:** $[\alpha]_D^{21}$ –7.4 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 92:8 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.3 min, τ_{major} = 7.0 min). See Supporting Information: Part B for HPLC chromatograms.

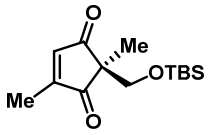


Compound 3la: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Yellow oil (20 mg, 0.073 mmol, 73% yield); **FT-IR (Thin film):** 2922 (m), 1640 (s), 1427 (m), 1261 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.20 (d, *J* = 8.4 Hz, 2H), 7.06 (d, *J* = 8.4 Hz, 2H), 6.67 (s, 1H), 5.13 (s, 1H), 4.99 (s, 1H), 2.93 (d, *J* = 13.6 Hz, 1H), 2.84 (d, *J* = 13.6 Hz, 1H), 1.75 (s, 3H), 1.15 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.1, 205.6, 160.8, 143.9, 143.1, 138.5, 133.8, 128.5, 128.4, 119.0, 51.3, 40.9, 19.5, 11.1; **HRMS (ESI+):** Calcd. for $C_{16}H_{16}ClO_2$ ($[M+H]^+$): 275.0839, Found: 275.0840; **Optical rotation:** $[\alpha]_D^{21}$ +1.7 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 97.5:2.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-1 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 9.6 min, τ_{major} = 11.1 min). See Supporting Information: Part B for HPLC chromatograms. [*Note*: This compound is sensitive to silica-gel and rapid chromatographic purification is necessary.]

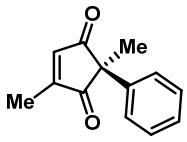


Compound 3ma: Purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); Yellow oil (14 mg, 0.078 mmol, 78% yield); **FT-IR (Thin film):** 2962 (m), 1745 (m), 1702 (s), 1457 (m), 1375 (w), 1256 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.93 (s, 1H), 2.09 (s, 3H), 1.63-1.60 (m, 2H), 1.40-1.33 (m, 1H), 1.07 (s, 3H), 0.71 (d, *J* = 6.6 Hz, 3H), 0.67 (d, *J* = 6.6 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 208.4, 207.0, 160.2, 143.9, 50.4, 43.8, 25.4, 24.0, 23.9, 21.4, 11.5; **HRMS (ESI+):** Calcd. for $C_{11}H_{16}O_2Na$ ($[M+Na]^+$): 203.1048, Found: 203.1047; **Optical rotation:** $[\alpha]_D^{21}$ –2.7 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 90:10 er. The

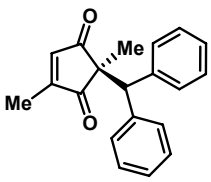
enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 5.8 min, τ_{major} = 6.8 min). See Supporting Information: Part B for HPLC chromatograms.



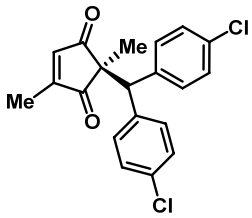
Compound 2na: Purified by silica gel-flash column chromatography (2-3% EtOAc in petroleum ether); Yellow oil (22 mg, 0.082 mmol, 82% yield); **FT-IR (Thin film):** 2931 (m), 1749 (m), 1705 (s), 1464 (m), 1271 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 6.99 (s, 1H), 3.73 (s, 2H), 2.09 (s, 3H), 0.97 (s, 3H), 0.72 (s, 9H), –0.08 (s, 6H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.4, 205.9, 161.6, 145.4, 65.9, 52.7, 25.6, 18.0, 14.0, 11.4, –5.7, –5.8; **HRMS (ESI+):** Calcd. for $C_{14}H_{24}O_3SiNa$ ($[M+Na]^+$): 291.1392, Found: 291.1393; **Optical rotation:** $[\alpha]_D^{21}$ –5.1 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 96:4 er. The enantiomeric ratio was determined (*after removal of TBS with 1:1 AcOH/H_2O at r.t. for 24 h*) by HPLC analysis using Phenomenex Cellulose-2 column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 11.9 min, τ_{minor} = 15.8 min). See Supporting Information: Part B for HPLC chromatograms.



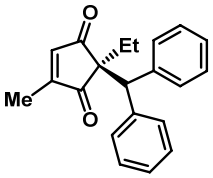
Compound 3oa: Purified by silica-gel flash column chromatography (2-4% EtOAc in petroleum ether); Light yellow oil (18 mg, 0.090 mmol, 90% yield); **FT-IR (Thin film):** 2929 (m), 1701 (s), 1541 (w), 1262 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.33-7.24 (m, 5H), 7.05 (s, 1H), 2.16 (s, 3H), 1.55 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 205.4, 204.1, 160.5, 144.2, 137.3, 128.8, 127.7, 126.5, 54.5, 19.9, 11.7; **HRMS (ESI+):** Calcd. for $C_{13}H_{12}O_2Na$ ($[M+Na]^+$): 223.0735, Found: 223.0739; **Optical rotation:** $[\alpha]_D^{21}$ –16.0 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 83.5:16.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 13.0 min, τ_{major} = 13.7 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3pa: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Yellow solid (25 mg, 0.086 mmol, 86% yield); **m.p.** 131-132 °C; **FT-IR (Thin film):** 2927 (m), 1741 (m), 1697 (s), 1492 (m), 1450 (m), 1375 (m), 1268 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.43-7.38 (m, 4H), 7.26-7.21 (m, 4H), 7.16-7.15 (m, 2H), 6.67 (s, 1H), 4.35 (s, 1H), 1.87 (s, 3H), 1.16 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 208.0, 206.3, 160.7, 144.3, 139.8, 129.6, 129.6, 128.5, 127.0, 57.7, 55.3, 18.6, 11.2; **HRMS (ESI+):** Calcd. for $C_{20}H_{18}O_2Na$ ($[M+Na]^+$): 313.1204, Found: 313.1210; **Optical rotation:** $[\alpha]_D^{21}$ +14.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 98:2 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IE column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 7.9 min, τ_{minor} = 11.2 min). See Supporting Information: Part B for HPLC chromatograms.

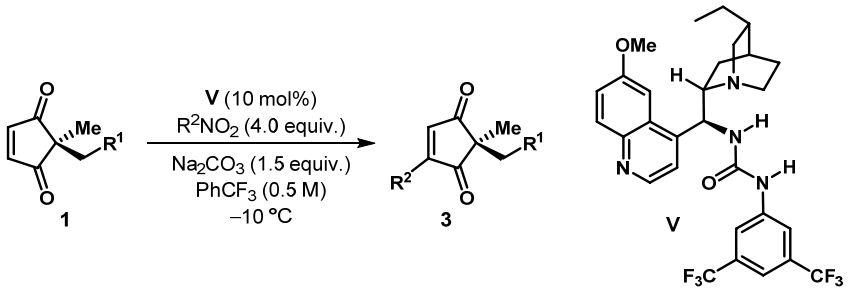


Compound 3qa: Purified by silica-gel flash column chromatography (4% EtOAc in petroleum ether); Yellow thick oil (30 mg, 0.083 mmol, 83% yield); **FT-IR (Thin film):** 2928 (m), 1717 (m), 1698 (s), 1490 (m), 1265 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.33-7.30 (m, 4H), 7.21-7.19 (m, 4H), 6.73 (s, 1H), 4.32 (s, 1H), 1.91 (s, 3H), 1.13 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.5, 205.7, 160.9, 144.4, 137.9, 137.8, 133.2, 130.9, 130.9, 128.8, 55.8, 54.9, 19.0, 11.3; **HRMS (ESI+):** Calcd. for $C_{20}H_{16}Cl_2O_2Na$ ($[M+Na]^+$): 381.0425, Found: 381.0421; **Optical rotation:** $[\alpha]_D^{21}$ –4.1 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 98:2 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 7.2 min, τ_{minor} = 7.7 min). See Supporting Information: Part B for HPLC chromatograms.



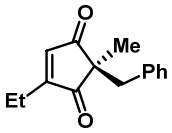
Compound 3ra: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Yellow amorphous solid (28 mg, 0.090 mmol, 90% yield); **m.p.** 121-122 °C; **FT-IR (Thin film):** 2930 (m), 1695 (s), 1638 (m), 1455 (m), 1260 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.42-7.37 (m, 4H), 7.25-7.20 (m, 4H), 7.17-7.14 (m, 2H), 6.73 (s, 1H), 4.32 (s, 1H), 1.85 (s, 3H), 1.75 (q, *J* = 7.4 Hz, 2H), 0.58 (t, *J* = 7.4 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 208.2, 206.5, 162.4, 146.0, 139.8, 129.6, 129.6, 128.5, 127.0, 60.5, 57.7, 26.3, 11.1, 9.2; **HRMS (ESI+):** Calcd. for $C_{21}H_{20}O_2Na$ ($[M+Na]^+$): 327.1361, Found: 327.1362; **Optical rotation:** $[\alpha]_D^{21}$ +8.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Daicel Chiralpak IE Column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 6.5 min, τ_{minor} = 11.4 min). See Supporting Information: Part B for HPLC chromatograms.

Typical procedure for the organocatalytic enantioselective C(sp^2)−H alkylation with other nitroalkanes:

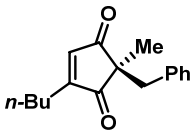


In an oven-dried Schlenk tube Na_2CO_3 (16.0 mg, 0.150 mmol, 1.5 equiv.) was taken and heated to 150 °C under high-vacuum for 15 min, cooled to r.t. under vacuum and purged with argon. Catalyst **V** (5.8 mg, 0.010 mmol, 0.10 equiv.) and 2-benzyl-2-methylcyclopent-4-ene-1,3-dione **1a** (20.0 mg, 0.100 mmol, 1.0 equiv.) was introduced under a positive argon pressure

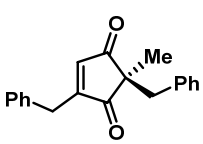
followed by 0.1 mL of absolute $PhCF_3$ and the suspension was cooled to –10 °C. After 10 min, a solution of nitroalkane (0.400 mmol, 4.0 equiv.) in 0.1 mL of absolute $PhCF_3$ was added to it and the resulting mixture was stirred at –10 °C until TLC (3 × 5% EtOAc in petroleum ether) revealed complete conversion of **1a**. The reaction mixture was diluted with 2 mL of CH_2Cl_2 and 2 mL of distilled water and slowly warmed to r.t. The resulting biphasic solution was transferred to a 50 mL separating funnel, organic phase was separated from aqueous phase. Aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). The combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure to obtain a reddish-brown oil. The crude reaction mixture was purified by silica-gel flash column chromatography.



Compound 3ab: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Thick yellow oil (17 mg, 0.074 mmol, 74% yield); **FT-IR (Thin film):** 2920 (m), 1681 (s), 1527 (s), 1443 (m), 1220 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.13-7.11 (m, 3H), 6.91-6.89 (m, 2H), 6.61 (s, 1H), 2.95 (s, 2H), 2.32-2.14 (m, 2H), 1.23 (s, 3H), 0.90 (t, J = 7.4 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.5, 206.3, 166.7, 142.9, 135.9, 129.7, 128.3, 127.0, 53.1, 41.4, 19.2, 18.8, 11.2; **HRMS (ESI+):** Calcd. for $C_{15}H_{16}O_2Na$ ($[M+Na]^+$): 251.1048, Found: 251.1047; **Optical rotation:** $[\alpha]_D^{21}$ +10.4 (*c* 0.5, $CHCl_3$) for an enantiomerically enriched sample with 95:5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.4 min, τ_{major} = 6.9 min). See Supporting Information: Part B for HPLC chromatograms.

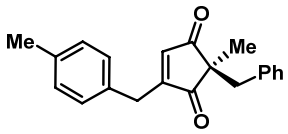


Compound 3ac: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Yellow oil (21 mg, 0.082 mmol, 82% yield); **FT-IR (Thin film):** 2930 (m), 1742 (m), 1698 (s), 1453 (m), 1248 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.14-7.08 (m, 3H), 6.90-6.88 (m, 2H), 6.61 (s, 1H), 2.97 (d, J = 13.1 Hz, 1H), 2.93 (d, J = 13.1 Hz, 1H), 2.21 (t, J = 7.3 Hz, 2H), 1.30-1.25 (m, 1H), 1.22 (s, 3H), 1.20-1.15 (m, 1H), 1.10-1.03 (m, 2H), 0.79 (t, J = 7.3 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.6, 206.4, 165.3, 143.5, 135.9, 129.7, 128.3, 127.0, 52.9, 41.3, 29.1, 25.0, 22.1, 19.4, 13.7; **HRMS (ESI+):** Calcd. for $C_{17}H_{20}O_2Na$ ($[M+Na]^+$): 279.1361, Found: 279.1360; **Optical rotation:** $[\alpha]_D^{25}$ +0.95 (*c* 1.5, $CHCl_3$) for an enantiomerically enriched sample with 85:15 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-3 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 5.6 min, τ_{minor} = 6.4 min). See Supporting Information: Part B for HPLC chromatograms.

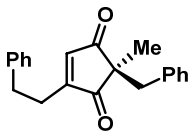


Compound 3ad: Purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether); Yellow oil (25 mg, 0.086 mmol, 86% yield); **FT-IR (Thin film):** 2927 (m), 1743 (m), 1700 (s), 1452 (m), 1249 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.22-7.21 (m, 3H), 7.15-7.12 (m, 3H), 6.89-6.88 (m,

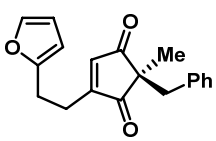
2H), 6.84-6.83 (m, 2H), 6.41 (s, 1H), 3.54 (d, *J* = 17.3 Hz, 1H), 3.47 (d, *J* = 17.3 Hz, 1H), 2.98 (s, 2H), 1.26 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.0, 205.9, 164.1, 144.5, 135.9, 135.8, 129.6, 128.9, 128.8, 128.4, 127.0, 127.0, 53.3, 41.5, 31.7, 19.1; **HRMS (ESI+):** Calcd. for $C_{20}H_{18}O_2Na$ ($[M+Na]^+$): 313.1204, Found: 313.1210; **Optical rotation:** $[\alpha]_D^{24}$ +51.4 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-1 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 9.3 min, τ_{minor} = 11.4 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3ae: Purified by silica-gel flash column chromatography (2% EtOAc in petroleum ether); Thick yellow oil (24 mg, 0.078 mmol, 78% yield); **FT-IR (Thin film):** 2923 (m), 1743 (m), 1700 (s), 1455 (m), 1248 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.13-7.10 (m, 3H), 7.02 (d, *J* = 7.6 Hz, 2H), 6.89-6.87 (m, 2H), 6.72 (d, *J* = 7.6 Hz, 2H), 6.40 (s, 1H), 3.50 (d, *J* = 17.3 Hz, 1H), 3.42 (d, *J* = 17.3 Hz, 1H), 2.97 (s, 2H), 2.30 (s, 3H), 1.24 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.1, 205.9, 164.5, 144.4, 136.6, 135.9, 132.8, 129.6, 129.5, 128.8, 128.4, 127.0, 53.3, 41.5, 31.3, 21.1, 19.1; **HRMS (ESI+):** Calcd. for $C_{21}H_{20}O_2Na$ ($[M+Na]^+$): 327.1361, Found: 327.1364; **Optical rotation:** $[\alpha]_D^{24}$ +25.8 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-1 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 8.3 min, τ_{minor} = 9.1 min). See Supporting Information: Part B for HPLC chromatograms.

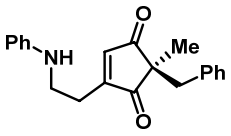


Compound 3af: Purified by silica-gel flash column chromatography (10% $CHCl_3$ in petroleum ether and then 2% EtOAc in petroleum ether); Yellow oil (27 mg, 0.088 mmol, 88% yield); **FT-IR (Thin film):** 2926 (m), 1741 (m), 1699 (s), 1454 (m), 1252 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.23-7.15 (m, 6H), 6.94-6.91 (m, 4H), 6.48 (s, 1H), 2.98 (s, 2H), 2.71-2.63 (m, 1H), 2.61-2.52 (m, 2H), 2.50-2.42 (m, 1H), 1.23 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.4, 206.2, 163.7, 144.0, 139.9, 136.0, 129.8, 128.6, 128.4, 128.3, 127.1, 126.5, 52.8, 41.2, 33.0, 26.8, 19.5; **HRMS (ESI+):** Calcd. for $C_{21}H_{20}O_2Na$ ($[M+Na]^+$): 327.1361, Found: 327.1360; **Optical rotation:** $[\alpha]_D^{24}$ +17.2 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 92.5:7.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 8.5 min, τ_{major} = 9.1 min). See Supporting Information: Part B for HPLC chromatograms.

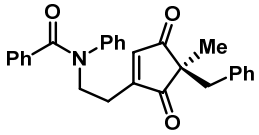


Compound 3ag: Purified by silica-gel flash column chromatography (10% $CHCl_3$ in petroleum ether and then 1% EtOAc in petroleum ether); Yellow oil (15 mg, 0.051 mmol, 51% yield); **FT-IR (Thin film):** 2943 (m), 1698 (s),

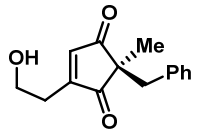
1448 (m), 1412 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.23 (br s, 1H), 7.15-7.13 (m, 3H), 6.92-6.90 (m, 2H), 6.51 (s, 1H), 6.19-6.18 (m, 1H), 5.72 (d, *J* = 2.8 Hz, 1H), 2.96 (s, 2H), 2.72 (dd, *J* = 13.8, 7.4 Hz, 1H), 2.60-2.56 (m, 2H), 2.53-2.47 (m, 1H), 1.23 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.3, 206.2, 163.3, 153.4, 144.0, 141.4, 135.9, 129.8, 128.4, 127.1, 110.2, 106.0, 52.9, 41.2, 25.4, 23.8, 19.4; **HRMS (ESI+):** Calcd. for $C_{19}H_{18}O_3Na$ ($[M+Na]^+$): 317.1154, Found: 317.1160; **Optical rotation:** $[\alpha]_D^{25}$ +10.5 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 93:7 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-1 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 210 nm, τ_{major} = 10.4 min, τ_{minor} = 12.1 min). See Supporting Information: Part B for HPLC chromatograms.



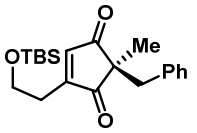
Compound 3ah: Purified by silica-gel flash column chromatography (40-50% CH_2Cl_2 in petroleum ether); Yellow oil (23 mg, 0.072 mmol, 72% yield); **FT-IR (Thin film):** 2921 (m), 1698 (s), 1629 (s), 1448 (m), 1219 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.19-7.12 (m, 5H), 6.96-6.95 (m, 2H), 6.70-6.67 (m, 1H), 6.62 (s, 1H), 6.41 (d, *J* = 7.9 Hz, 2H), 3.25-3.19 (m, 1H), 3.02 (d, *J* = 13.0 Hz, 1H), 2.96 (d, *J* = 13.0 Hz, 1H), 2.87-2.80 (m, 1H), 2.59-2.51 (m, 2H), 1.25 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.7, 206.1, 162.1, 146.8, 145.7, 136.2, 129.9, 129.5, 128.5, 127.3, 117.8, 112.9, 52.8, 41.6, 40.9, 25.1, 19.0; **HRMS (ESI+):** Calcd. for $C_{21}H_{22}NO_2$ ($[M+H]^+$): 320.1651, Found: 320.1652; **Optical rotation:** $[\alpha]_D^{25}$ +88.3 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 90:10 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (80:20 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 6.1 min, τ_{major} = 6.9 min). See Supporting Information: Part B for HPLC chromatograms. [*Note*: This compound is sensitive to silica-gel and rapid chromatographic purification is necessary.]



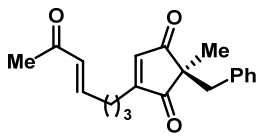
Compound 3ai: Purified by silica-gel flash column chromatography (80% CH_2Cl_2 in petroleum ether); Thick yellow oil (38 mg, 0.090 mmol, 90% yield); **FT-IR (Thin film):** 2924 (m), 1699 (s), 1647 (s), 1457 (m), 1395 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.22-7.11 (m, 11H), 6.92-6.89 (m, 4H), 6.75 (s, 1H), 3.94-3.90 (m, 2H), 2.97 (d, *J* = 13.1 Hz, 1H), 2.93 (d, *J* = 13.1 Hz, 1H), 2.68-2.60 (m, 1H), 2.58-2.50 (m, 1H), 1.21 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.2, 206.1, 170.6, 161.7, 144.2, 142.7, 135.9, 135.5, 129.9, 129.7, 129.4, 128.7, 128.3, 127.8, 127.8, 127.1, 127.0, 52.7, 47.6, 41.2, 24.1, 19.1; **HRMS (ESI+):** Calcd. for $C_{28}H_{25}NO_3Na$ ($[M+Na]^+$): 446.1732, Found: 446.1726; **Optical rotation:** $[\alpha]_D^{25}$ –26.6 (*c* 3.0, $CHCl_3$) for an enantiomerically enriched sample with 91:9 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (80:20 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 14.0 min, τ_{major} = 15.6 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3aj: Purified by silica-gel flash column chromatography (80% CH_2Cl_2 in petroleum ether); Thick yellow oil (20 mg, 0.082 mmol, 82% yield); **FT-IR (Thin film):** 2933 (m), 1670 (s), 1525 (m), 1443 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.16-7.15 (m, 3H), 6.93-6.91 (m, 2H), 6.78 (s, 1H), 3.61-3.54 (m, 1H), 3.41-3.34 (m, 1H), 3.01 (d, *J* = 13.0 Hz, 1H), 2.94 (d, *J* = 13.0 Hz, 1H), 2.51-2.47 (m, 2H), 1.25 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.9, 206.2, 161.7, 145.9, 136.0, 129.8, 128.4, 127.2, 59.7, 52.8, 41.6, 29.1, 19.0; **HRMS (ESI+):** Calcd. for $C_{15}H_{16}O_3Na$ ($[M+Na]^+$): 267.0997, Found: 267.0997; **Optical rotation:** $[\alpha]_D^{24}$ +11.5 (*c* 1.0, $CHCl_3$) for an enantiomerically enriched sample with 77.5:22.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (95:5 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 20.0 min, τ_{minor} = 20.9 min). See Supporting Information: Part B for HPLC chromatograms.

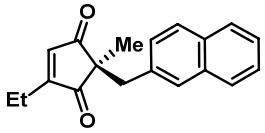


Compound 3ak: Purified by silica-gel flash column chromatography (5% $CHCl_3$ in petroleum ether and then 2% EtOAc in petroleum ether); Yellow oil (33 mg, 0.092 mmol, 92% yield); **FT-IR (Thin film):** 2930 (m), 1647 (s), 1577 (w), 1260 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.12-7.11 (m, 3H), 6.90-6.88 (m, 2H), 6.76 (s, 1H), 3.62-3.57 (m, 1H), 3.45-3.40 (m, 1H), 2.97 (d, *J* = 13.3 Hz, 1H), 2.93 (d, *J* = 13.3 Hz, 1H), 2.50-2.35 (m, 2H), 1.22 (s, 3H), 0.81 (s, 9H), –0.02 (s, 3H), –0.03 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.6, 206.4, 162.0, 144.8, 135.9, 129.7, 128.3, 127.0, 60.0, 52.6, 41.3, 28.6, 25.9, 19.3, 18.2, –5.3; **HRMS (ESI+):** Calcd. for $C_{21}H_{30}O_3SiNa$ ($[M+Na]^+$): 381.1862, Found: 381.1867; **Optical rotation:** $[\alpha]_D^{21}$ +6.3 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er. The enantiomeric ratio was determined (*after the removal of TBS with 1:1 AcOH/H_2O at r.t. for 18 h*) by HPLC analysis using Phenomenex Cellulose-2 column (95:5 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 20.1 min, τ_{minor} = 21.0 min). See Supporting Information: Part B for HPLC chromatograms.



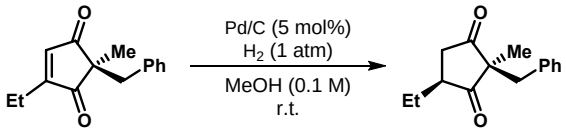
Compound 3al: Purified by silica-gel flash column chromatography (5% EtOAc in petroleum ether); Yellow oil (25 mg, 0.080 mmol, 80% yield); **FT-IR (Thin film):** 2930 (m), 1701 (s), 1455 (m), 1225 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.11-7.10 (m, 3H), 6.89-6.87 (m, 2H), 6.66-6.58 (m, 2H), 5.97 (d, *J* = 15.9 Hz, 1H), 2.98 (d, *J* = 13.1 Hz, 1H), 2.93 (d, *J* = 13.1 Hz, 1H), 2.31-2.23 (m, 2H), 2.22 (s, 3H), 1.93 (q, *J* = 7.2 Hz, 2H), 1.49-1.33 (m, 2H), 1.22 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.3, 206.1, 198.4, 164.0, 146.4, 143.8, 135.8, 131.8, 129.7, 128.3, 127.0, 52.9, 41.3, 31.4, 27.1, 25.3, 24.7, 19.3; **HRMS (ESI+):** Calcd. for $C_{20}H_{22}O_3Na$ ($[M+Na]^+$): 333.1467, Found: 333.1465; **Optical rotation:** $[\alpha]_D^{24}$ –1.9 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 88:12 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20

°C, 254 nm, τ_{minor} = 15.9 min, τ_{major} = 17.5 min). See Supporting Information: Part B for HPLC chromatograms.



Compound 3fb: Purified by silica-gel flash column chromatography (2-3% EtOAc in petroleum ether); Thick yellow oil (22 mg, 0.079 mmol, 79% yield); **FT-IR (Thin film):** 2930 (m), 1698 (s), 1457 (m), 1216 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.72-7.68 (m, 2H), 7.61 (d, *J* = 8.4 Hz, 1H), 7.42-7.36 (m, 3H), 7.02 (d, *J* = 8.4 Hz, 1H), 6.56 (s, 1H), 3.13 (s, 2H), 2.27-2.09 (m, 2H), 1.28 (s, 3H), 0.78 (t, *J* = 7.4 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.4, 206.1, 166.5, 142.9, 133.5, 133.2, 132.3, 128.5, 127.9, 127.8, 127.7, 127.5, 126.0, 125.7, 53.1, 41.4, 19.4, 18.7, 11.1; **HRMS (ESI+):** Calcd. for $C_{19}H_{18}O_2Na$ ($[M+Na]^+$): 301.1204, Found: 301.1205; **Optical rotation:** $[\alpha]_D^{23}$ –4.0 (*c* 2.2, $CHCl_3$) for an enantiomerically enriched sample with 92.5:7.5 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (99:1 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 8.2 min, τ_{major} = 9.4 min). See Supporting Information: Part B for HPLC chromatograms.

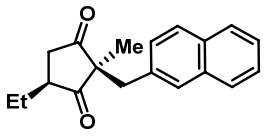
Procedure for hydrogenation of 3ab:



3ab (93:7 er) **4a**

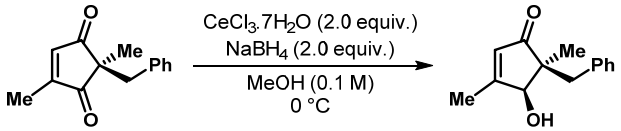
In an oven-dried 10 mL round-bottom flask, **3ab** (80 mg, 0.350 mmol, 1.0 equiv.) was taken in 3.5 mL of absolute MeOH. To this was added 10% Pd/C (18.6 mg, 0.0175 mmol, 0.05 equiv.) and the resulting suspension was stirred at r.t. under H_2-balloon pressure. After 3 h, the reaction mixture was diluted with 5 mL of MeOH and filtered through a pad of celite. The filtrate was collected and concentrated under reduced pressure. The crude mass was purified by silica-gel flash column chromatography (1-2% EtOAc in petroleum ether) to obtain **4a** as a colorless oil as a single diastereoisomer (18 mg, 0.078 mmol, 22% yield); **FT-IR (Thin film):** 2928 (m), 1723 (s), 1451 (m), 1320 (w), 1229 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.21-7.16 (m, 3H), 7.02-7.00 (m, 2H), 3.01 (d, *J* = 12.9 Hz, 1H), 2.91 (d, *J* = 12.9 Hz, 1H), 2.75 (dd, *J* = 18.3, 9.9 Hz, 1H), 2.58-2.49 (m, 1H), 1.60-1.53 (m, 3H), 1.21 (s, 3H), 0.85-0.75 (m, 1H), 0.70 (t, *J* = 7.2 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 218.6, 216.8, 136.3, 130.0, 128.4, 127.1, 59.0, 47.9, 42.5, 41.6, 22.6, 21.6, 11.6; **HRMS (ESI+):** Calcd. for $C_{15}H_{18}O_2Na$ ($[M+Na]^+$): 253.1204, Found: 253.1204; The absolute configurations of **4a** was assigned as (2*R*,4*S*) by comparing the NMR and specific rotation with the known compound.[8] **Optical rotation:** $[\alpha]_D^{25}$ +47.5 (*c* 2.0, $CHCl_3$) [Lit[8] +53.5 (*c* 1.1, $CHCl_3$) for an enantiomerically enriched sample with 94:6 er].

(8) Aikawa, K.; Okamoto, T.; Mikami, K. *J. Am. Chem. Soc.* **2012**, *134*, 10329.



Compound 4b: The above mentioned procedure was followed starting from **3fb** (with 92.5:7.5 er). Purified by silica-gel flash column chromatography (1-3% EtOAc in petroleum ether); Colorless oil (38 mg, 0.135 mmol, 47% yield); **FT-IR (Thin film):** 2927 (m), 1720 (s), 1450 (m), 1320 (m), 1224 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.77-7.73 (m, 2H), 7.69 (d, *J* = 8.4 Hz, 1H), 7.50 (s, 1H), 7.45-7.40 (m, 2H), 7.15 (d, *J* = 8.4 Hz, 1H), 3.21 (d, *J* = 12.9 Hz, 1H), 3.06 (d, *J* = 12.9 Hz, 1H), 2.73 (dd, *J* = 18.3, 9.9 Hz, 1H), 2.59-2.51 (m, 1H), 1.61-1.48 (m, 2H), 1.26 (s, 3H), 0.83-0.72 (m, 1H), 0.62 (t, *J* = 7.5 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 218.6, 216.6, 134.0, 133.3, 132.3, 128.8, 128.2, 128.0, 127.8, 127.6, 126.2, 125.8, 59.1, 47.9, 42.7, 41.6, 22.6, 21.9, 11.6; **HRMS (ESI+):** Calcd. for $C_{19}H_{20}O_2Na$ ($[M+Na]^+$): 303.1361, Found: 303.1361; The absolute configurations of **4b** was assigned as (2*R*,4*S*) by comparing the NMR and specific rotation with the known compound.[8] **Optical rotation:** $[\alpha]_D^{23}$ +76.4 (*c* 2.0, $CHCl_3$) [Lit[8] +61.2 (*c* 0.45, $CHCl_3$) for an enantiomerically enriched sample with 85:15 er].

Procedure for the selective reduction of 3aa:

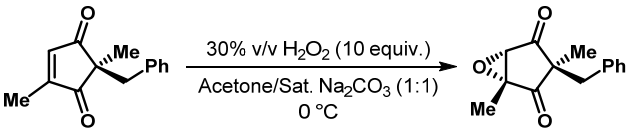


3aa (97:3 er) **5**

In an oven dried 10 mL 2-necked round-bottom flask, **3aa** (50 mg, 0.233 mmol, 1.0 equiv.) and $CeCl_3.7H_2O$ (174 mg, 0.467 mmol, 2.0 equiv.) was taken in 2.3 mL of absolute methanol under Argon and the resulting solution was cooled to 0 °C. To this was added $NaBH_4$ (18 mg, 0.467 mmol, 2.0 equiv.) at once and the resulting mixture was stirred at 0 °C. After 10 min, reaction mixture was quenched with 2 mL of sat. NH_4Cl solution and diluted with 5 mL CH_2Cl_2. Organic phase was separated from aqueous phase, aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture (with rr 65:1 and dr = 5:1, as obtained from ^{1}H-NMR) was purified by silica-gel flash column chromatography (10% EtOAc in petroleum ether) to obtain the major diastereoisomer in pure form as a colorless thick oil (28 mg, 0.129 mmol, 55% yield); **FT-IR (Thin film):** 2924 (m), 1685 (s), 1647 (s), 1457 (w), 1260 (w), 1211 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.24-7.22 (m, 2H), 7.19-7.16 (m, 3H), 7.03 (s, 1H), 4.48 (s, 1H), 2.97 (d, *J* = 13.7 Hz, 1H), 2.84 (d, *J* = 13.7 Hz, 1H), 1.74 (s, 3H), 1.11 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 210.6, 154.3, 141.8, 138.0, 130.6, 128.2, 126.5, 78.7, 53.3, 39.6, 22.2, 10.3; **HRMS (ESI+):** Calcd. for $C_{14}H_{16}O_2Na$ ($[M+Na]^+$): 239.1048, Found: 239.1046; **Optical rotation:** $[\alpha]_D^{21}$ –87.6 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 97:3 er. The enantiomeric ratio was determined by HPLC analysis using Phenomenex Cellulose-2 column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{major} = 6.5 min, τ_{minor} = 7.2 min).

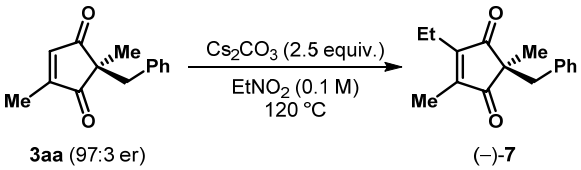
See Supporting Information: Part B for HPLC chromatograms. The relative stereochemistry was determined by 1D NOE experiment (See Supporting Information: Part B).

Procedure for epoxidation of 3aa:



In a 10 mL round-bottom flask, **3aa** (21.4 mg, 0.100 mmol, 1.0 equiv.) was taken in 1.0 mL of acetone/20% aq. Na_2CO_3 (1:1). To this was added 30% v/v aq. H_2O_2 (120 µL, 1.00 mmol, 10 equiv.) and the resulting solution was vigorously stirred at 0 °C. After 4 h at 0 °C, the reaction mixture was brought to r.t. and concentrated under reduced pressure. The residue was diluted with 5 mL of CH_2Cl_2 and 5 mL of distilled water. Organic phase was separated from the aqueous phase. The aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel flash column chromatography (1% EtOAc in petroleum ether) to obtain **6** as a colorless oil, essentially as a single diastereoisomer (18 mg, 0.078 mmol, 78% yield); **FT-IR (Thin film):** 2926 (m), 1736 (m), 1693 (s), 1450 (m), 1373 (m), 1255 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.21-7.16 (m, 3H), 6.97-6.95 (m, 2H), 3.34 (s, 1H), 3.00 (d, *J* = 12.8 Hz, 1H), 2.94 (d, *J* = 12.8 Hz, 1H), 1.30 (s, 3H), 1.22 (s, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 206.3, 205.8, 135.0, 130.0, 128.6, 127.4, 64.4, 62.1, 55.1, 43.3, 21.8, 9.1; **Optical rotation:** $[\alpha]_D^{25}$ –14.9 (*c* 1.0, $CHCl_3$). The relative stereochemistry was determined by 1D NOE experiment (See Supporting Information: Part B).

Typical procedure for the second alkylation:

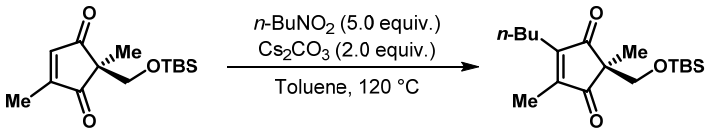


In an oven and vacuum-dried 10 mL round-bottom flask, equipped with a reflux condenser, Cs_2CO_3 (95 mg, 0.291 mmol, 2.5 equiv.) was taken and heated at 150 °C under vacuum for 2 h, cooled to r.t. and flashed with Ar. To this was added **3aa** (25 mg, 0.116 mmol, 1.0 equiv.) followed by 1.2 mL of nitroethane and the resulting suspension was refluxed at 120 °C under Ar. After 4 h, reaction mixture was cooled to r.t., diluted with 2 mL of distilled water and 5 mL of CH_2Cl_2. Organic phase was separated from aqueous phase, aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by

silica-gel flash column chromatography (2-3% EtOAc in petroleum ether) to obtain **7** as a yellow oil (25 mg, 0.104 mmol, 90% yield); **FT-IR (Thin film):** 2931 (m), 1739 (m), 1694 (s), 1636 (m), 1454 (m), 1339 (m), 1249 (w); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 7.10-7.08 (m, 3H), 6.87-6.86 (m, 2H), 2.96 (d, *J* = 13.0 Hz, 1H), 2.91 (d, *J* = 13.0 Hz, 1H), 2.31-2.22 (m, 1H), 2.17-2.08 (m, 1H), 1.74 (s, 3H), 1.20 (s, 3H), 0.71 (t, *J* = 7.6 Hz, 3H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 207.2, 206.4, 159.9, 154.2, 136.1, 129.6, 128.2, 126.9, 51.5, 41.7, 19.1, 17.0, 11.9, 8.7; **HRMS (ESI+):** Calcd. for $C_{16}H_{18}O_2Na$ ($[M+Na]^+$): 265.1204, Found: 265.1204; **Optical rotation:** $[\alpha]_D^{21}$ –20.2 (*c* 2.0, $CHCl_3$).

The enantiomeric compound (+)-**7** was synthesized from **3ab** (with 95:5 er) and nitromethane following the above procedure (87% yield). **Optical rotation:** $[\alpha]_D^{21}$ +18.4 (*c* 1.5, $CHCl_3$).

Procedure for the alkylation of 3na:



In an oven and vacuum-dried 10 mL round-bottom flask, equipped with reflux condenser, Cs_2CO_3 (78 mg, 0.222 mmol, 2.0 equiv.) was taken and heated at 150 °C under vacuum for 2 h, cooled to r.t. and flashed with Ar. To this was added a solution of **3an** (30 mg, 0.111 mmol, 1.0 equiv.) and 1-nitrobutane (58 mg, 0.555 mmol, 5.0 equiv.) in 1.1 mL of absolute toluene and the resulting suspension was refluxed at 120 °C under Ar. After 12 h, reaction mixture was cooled to r.t., diluted with 5 mL of distilled water and 5 mL of CH_2Cl_2. Organic phase was separated from the aqueous phase. The aqueous phase was extracted with additional CH_2Cl_2 (2 × 5 mL). Combined organic phase was dried over anh. Na_2SO_4 and concentrated under reduced pressure. The crude reaction mixture was purified by silica-gel flash column chromatography (2-4% EtOAc in petroleum ether) to obtain **8** as a light yellow oil (29 mg, 0.089 mmol, 80% yield); **FT-IR (Thin film):** 2931 (m), 2859 (m), 1743 (m), 1698 (s), 1460 (m), 1383 (m), 1289 (m); **^{1}H-NMR (400 MHz, $CDCl_3$):** δ 3.71 (s, 2H), 2.50-2.37 (m, 2H), 1.99 (s, 3H), 1.48-1.41 (m, 2H), 1.38-1.28 (m, 2H), 0.93 (s, 3H), 0.89 (t, *J* = 7.2 Hz, 3H), 0.70 (s, 9H), –0.09 (s, 6H); **^{13}C-NMR (100 MHz, $CDCl_3$):** δ 206.7, 206.3, 159.5, 155.2, 66.0, 51.6, 30.0, 25.6, 23.9, 22.9, 18.0, 14.3, 13.9, 9.2, –5.7, –5.8; **HRMS (ESI+):** Calcd. for $C_{18}H_{32}O_3SiNa$ ($[M+Na]^+$): 347.2018, Found: 347.2014; **Optical rotation:** $[\alpha]_D^{23}$ +1.1 (*c* 2.0, $CHCl_3$) for an enantiomerically enriched sample with 96:4 er. The enantiomeric ratio was determined (*after removal of TBS with 1:1 AcOH/H_2O at r.t. for 36 h*) by HPLC analysis using Phenomenex Cellulose-2 column (90:10 *n*-Hexane/EtOH, 1.0 mL/min, 20 °C, 254 nm, τ_{minor} = 7.3 min, τ_{major} = 7.8 min). See Supporting Information: Part B for HPLC chromatograms.

Single crystal X-ray diffraction analysis of 3aa:

A single crystal of **3aa** (recrystallized from 1:1 petroleum ether/EtOAc at 0 °C) was mounted and the diffraction data were collected at 100 K on a Bruker SMART APEX CCD diffractometer using SMART/SAINT software. Intensity data were collected using graphite-monochromatized Mo-Ka radiation (0.71073 Å). The structures were solved by direct methods using the SHELX-97 and refined by full-matrix least-squares on F^2. Empirical absorption corrections were applied with SADABS. All Non-hydrogen atoms were refined anisotropically and hydrogen atoms were included in geometric positions. Structure was drawn using Olex-2 and ORTEP-3. The crystallographic refinement parameters are given below:

Table 6. Crystal data and structure refinement for 3aa

Identification code	**3aa**
Empirical formula	$C_{14}H_{14}O_2$
Formula weight	214.25
Temperature	100(2) K
Wavelength	0.71073 Å
Crystal system	Orthorhombic
Space group	$P2_12_12_1$
Unit cell dimensions	a = 7.0960(10) Å α = 90°
	b = 10.3820(15) Å β = 90°
	c = 15.619(2) Å γ = 90°
Volume	1150.6(3) $Å^3$
Z	4
Density (calculated)	1.237 Mg/m^3
Absorption coefficient	0.082 mm^{-1}
F(000)	456
Crystal size	0.50 × 0.12 × 0.10 mm^3
Theta range for data collection	2.36 to 27.52°
Limiting indices	$-8 \le h \le 9, -13 \le k \le 13, -20 \le l \le 19$
Reflections collected	18045
Independent reflections	2633 [R_{int} = 0.0589]
Completeness to Θ = 27.52	99.5 %
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	2633 / 0 / 147
Goodness-of-fit on F^2	1.070
Final R indices [I > 2 σ (I)]	R1 = 0.0387, ω R2 = 0.1000
R indices (all data)	R1 = 0.0408, ω R2 = 0.1016

Absolute structure parameter	–0.01(4)
Largest diff. peak and hole	0.381 and –0.367 e.A^{-3}

Table 7. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$ × 10^3) for 3aa. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
O(1)	-776(2)	1742(1)	-6258(1)	30(1)
O(2)	-1083(2)	-2778(1)	-5984(1)	33(1)
C(1)	-3901(2)	1256(2)	-4995(1)	35(1)
C(2)	-2748(2)	284(1)	-5455(1)	24(1)
C(3)	-1182(2)	648(1)	-6051(1)	21(1)
C(4)	-194(2)	-570(1)	-6360(1)	20(1)
C(5)	-232(2)	-681(1)	-7349(1)	22(1)
C(6)	-2179(2)	-597(1)	-7742(1)	20(1)
C(7)	-3361(2)	-1668(1)	-7773(1)	28(1)
C(8)	-5152(2)	-1569(2)	-8131(1)	36(1)
C(9)	-5766(2)	-425(2)	-8480(1)	37(1)
C(10)	-1371(2)	-1625(1)	-5925(1)	23(1)
C(11)	-2848(2)	-1003(1)	-5408(1)	27(1)
C(12)	1855(2)	-605(2)	-6035(1)	30(1)
C(13)	-2823(2)	558(1)	-8091(1)	26(1)
C(14)	-4604(2)	640(2)	-8461(1)	33(1)

Table 8. Bond lengths [Å] and angles [°] for 3aa

O(1)-C(3)	1.2149(16)
O(2)-C(10)	1.2183(16)
C(1)-C(2)	1.4841(19)
C(1)-H(1A)	0.9600
C(1)-H(1B)	0.9600
C(1)-H(1C)	0.9600
C(2)-C(11)	1.340(2)
C(2)-C(3)	1.4978(18)
C(3)-C(4)	1.5247(17)
C(4)-C(10)	1.5363(18)
C(4)-C(12)	1.5407(17)
C(4)-C(5)	1.5492(16)

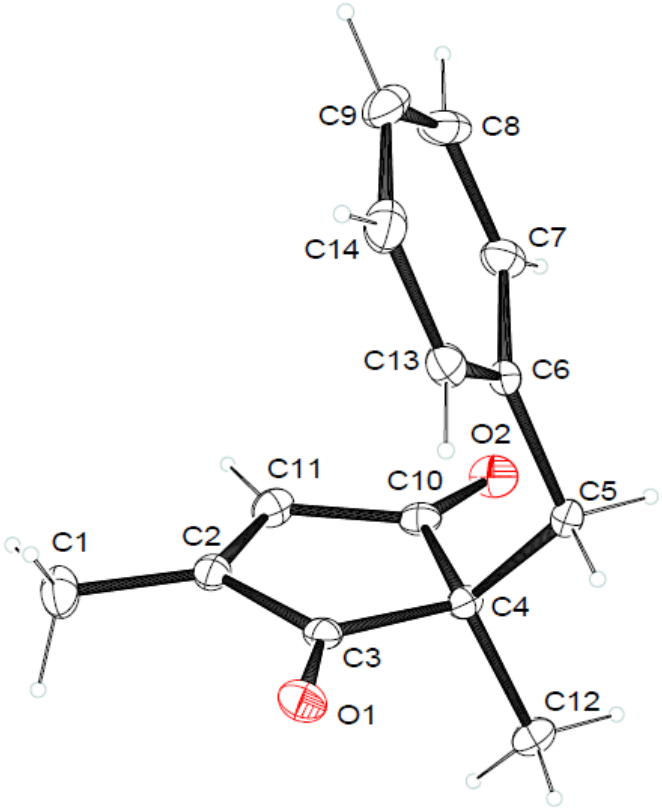
C(5)-C(6)	1.5139(17)
C(5)-H(5A)	0.9700
C(5)-H(5B)	0.9700
C(6)-C(7)	1.3935(19)
C(6)-C(13)	1.3947(19)
C(7)-C(8)	1.393(2)
C(7)-H(7)	0.9300
C(8)-C(9)	1.378(2)
C(8)-H(8)	0.9300
C(9)-C(14)	1.380(2)
C(9)-H(9)	0.9300
C(10)-C(11)	1.472(2)
C(11)-H(11)	0.9300
C(12)-H(12A)	0.9600
C(12)-H(12B)	0.9600
C(12)-H(12C)	0.9600
C(13)-C(14)	1.392(2)
C(13)-H(13)	0.9300
C(14)-H(14)	0.9300

C(2)-C(1)-H(1A)	109.5
C(2)-C(1)-H(1B)	109.5
H(1A)-C(1)-H(1B)	109.5
C(2)-C(1)-H(1C)	109.5
H(1A)-C(1)-H(1C)	109.5
H(1B)-C(1)-H(1C)	109.5
C(11)-C(2)-C(1)	128.46(13)
C(11)-C(2)-C(3)	108.97(11)
C(1)-C(2)-C(3)	122.55(12)
O(1)-C(3)-C(2)	125.25(12)
O(1)-C(3)-C(4)	125.56(12)
C(2)-C(3)-C(4)	109.20(10)
C(3)-C(4)-C(10)	101.58(10)
C(3)-C(4)-C(12)	110.43(11)
C(10)-C(4)-C(12)	110.51(11)
C(3)-C(4)-C(5)	111.70(10)
C(10)-C(4)-C(5)	112.30(10)

C(12)-C(4)-C(5)	110.08(11)
C(6)-C(5)-C(4)	114.54(10)
C(6)-C(5)-H(5A)	108.6
C(4)-C(5)-H(5A)	108.6
C(6)-C(5)-H(5B)	108.6
C(4)-C(5)-H(5B)	108.6
H(5A)-C(5)-H(5B)	107.6
C(7)-C(6)-C(13)	118.39(12)
C(7)-C(6)-C(5)	121.17(12)
C(13)-C(6)-C(5)	120.44(11)
C(8)-C(7)-C(6)	120.28(14)
C(8)-C(7)-H(7)	119.9
C(6)-C(7)-H(7)	119.9
C(9)-C(8)-C(7)	120.76(14)
C(9)-C(8)-H(8)	119.6
C(7)-C(8)-H(8)	119.6
C(8)-C(9)-C(14)	119.54(13)
C(8)-C(9)-H(9)	120.2
C(14)-C(9)-H(9)	120.2
O(2)-C(10)-C(11)	126.32(13)
O(2)-C(10)-C(4)	125.16(13)
C(11)-C(10)-C(4)	108.49(11)
C(2)-C(11)-C(10)	111.70(12)
C(2)-C(11)-H(11)	124.2
C(10)-C(11)-H(11)	124.2
C(4)-C(12)-H(12A)	109.5
C(4)-C(12)-H(12B)	109.5
H(12A)-C(12)-H(12B)	109.5
C(4)-C(12)-H(12C)	109.5
H(12A)-C(12)-H(12C)	109.5
H(12B)-C(12)-H(12C)	109.5
C(14)-C(13)-C(6)	120.81(13)
C(14)-C(13)-H(13)	119.6
C(6)-C(13)-H(13)	119.6
C(9)-C(14)-C(13)	120.19(14)
C(9)-C(14)-H(14)	119.9
C(13)-C(14)-H(14)	119.9

Table 9. Anisotropic displacement parameters ($Å^2 \times 10^3$) for 3aa. The anisotropic displacement factor exponent takes the form: $-2\pi^2[h^2a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O(1)	35(1)	22(1)	32(1)	-2(1)	-2(1)	-4(1)
O(2)	36(1)	23(1)	40(1)	5(1)	-8(1)	2(1)
C(1)	37(1)	42(1)	28(1)	-4(1)	5(1)	9(1)
C(2)	21(1)	33(1)	17(1)	-1(1)	-3(1)	2(1)
C(3)	20(1)	23(1)	20(1)	-2(1)	-5(1)	-1(1)
C(4)	17(1)	22(1)	22(1)	0(1)	-1(1)	-1(1)
C(5)	17(1)	27(1)	22(1)	-3(1)	3(1)	1(1)
C(6)	18(1)	24(1)	18(1)	-5(1)	2(1)	-1(1)
C(7)	31(1)	27(1)	25(1)	-2(1)	0(1)	-7(1)
C(8)	29(1)	53(1)	25(1)	-3(1)	-1(1)	-20(1)
C(9)	19(1)	72(1)	21(1)	-1(1)	-1(1)	1(1)
C(10)	23(1)	23(1)	24(1)	4(1)	-7(1)	-1(1)
C(11)	24(1)	33(1)	23(1)	6(1)	1(1)	-3(1)
C(12)	18(1)	37(1)	35(1)	-1(1)	-5(1)	2(1)
C(13)	28(1)	27(1)	22(1)	-3(1)	1(1)	0(1)
C(14)	31(1)	44(1)	26(1)	0(1)	1(1)	12(1)



ORTEP representation of the X-ray structure of enantiopure **3aa** (thermal ellipsoids at 30% probability)