Supporting Information

Room Temperature Hydroalkylation of Electron-Deficient Olefins: Sp^3 C-H Functionalization via a Lewis Acid-Catalyzed Intramolecular Redox Event.

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I. General.

Argon was purified by passage through Drierite. Nuclear Magnetic Resonance spectra were recorded on Bruker 300 or 400 or 500 Fourier transform NMR spectrometers. Spectra recorded in CDCl_3 or DMSO solutions and were referenced to TMS or the solvent residual peak. IR spectra were taken neat on NaCl plates using a Perkin-Elmer 1600 FTIR spectrometer. Flash chromatography was performed on SILICYCLE silica gel (230-400 mesh). Mass spectra were recorded on a JEOL LCmate (Ionization mode: APCI+).

II. Synthesis of Starting Material.

Synthesis of Enal (1a).

To a 500 mL round bottom flask containing 300 mL of DMF/toluene (1:1) was added NaH (7.92 g, 313 mmol, 2.0 equiv, 95 %) under argon. Diethyl malonate (47.5 mL, 313 mmol, 2.0 equiv) was added portion wise (slowly) via syringe. After stirring for 30 minutes at room temperature, 2-Bromomethyl-tetrahydro-pyran (20 mL, 156 mmol) was added via syringe in one portion. The resulting reaction mixture was heated to 95 °C overnight (~16 h) and quenched in a 1000 mL separatory funnel containing 100 mL water. 500 mL of ether and 250 mL hexanes was added and the layers separated. The organic layer was washed with water (1 X 100 mL, 3 X 50 mL) and brine, dried over MgSO_4 and concentrated *in vacuo*. Vacuum distillation (~ 1 mmHg) of the residual oil through a Vigreux column (10 cm) gave **S1** (28.4 g, 71% yield, bp 124 °C; ~ 1 mmHg): as a colorless oil: IR 2937, 2847, 1747, 1732, 1443, 1370, 1269, 1235, 1177, 1155, 1090, 1044; ^1H NMR CDCl_3 , 300 MHz) δ 1.20-1.30 (m, 6H), 1.45-1.57 (m, 4H),

1.61-1.82 (m, 1H), 1.92-2.16 (m, 2H), 3.20-3.24 (m, 1H), 3.26-3.38 (m, 1H), 3.62 (dd, $J = 9.0, 5.6$ Hz, 1H), 3.90-3.94 (m, 1H), 4.13-4.24 (m, 4H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 14.0, 14.1, 23.3, 25.9, 31.9, 35.3, 48.4, 61.2, 68.3, 75.1, 160.5, 169.8.

To a solution of **S1** (2.15 g, 8.32 mmol) in 80 mL of DMF/toluene under argon was added NaH (231 mg, 9.16 mmol, 1.1 equiv, 95%) in one portion. After stirring 20 minutes, the allylic bromide **S2** (2.15 g, 9.16 mmol, 1.1 equiv) was added and the reaction stirred for 2 hours at room temperature. The reaction was quenched by the addition of 20 mL of water. 175 mL of ether was added and the layers separated. The organic layer was washed with water (4 X 10 mL) and brine, dried over MgSO_4 , and concentrated *in vacuo*. The resulting crude oil was dissolved in 125 mL of absolute ethanol and a catalytic amount of *p*-toluenesulfonic acid monohydrate (c.a 100 mg) was added. The resulting solution was refluxed for 36 hours and then the solvent was removed *in vacuo*. The crude residue was filtered through a short plug of silica gel (Hex:EtOAc = 1:1) to remove the residual acid. The resulting oil was dissolved in 40 mL of CH_2Cl_2 and 3.2 g of NaOAc (1g NaOAc/ g PCC) was added. To the vigorously stirred suspension was added PCC (3.2 g, 15.0 mmol, 1.8 equiv). After stirring overnight, 100 mL of ether was added the reaction filtered through a fritted funnel containing a layer celite and silica gel. Purification of the residual via flash chromatography (Hex:EtOAc = 2:1) gave **1a** as a colorless oil (2.0 g, 74% yield for three steps): IR 2938, 2847, 1733, 1696, 1653, 1203, 1188, 1092, 1029 cm^{-1} ; ^1H NMR (CDCl_3 , 300 MHz) δ 1.22-1.27 (m, 6H), 1.30-1.40 (m, 4H), 1.43-1.52 (m, 4H), 1.79-1.82 (m, 2H), 1.97-2.16 (m, 2H), 2.89-3.09 (m, 2H), 3.23-3.33 (m, 2H), 3.81-3.86 (m, 2H), 4.13-4.23 (m, 4H), 6.11 (dd, $J = 15.5, 7.8$ Hz, 1H), 6.77 (pentet, $J_{\text{av}} = 7.6$ Hz, 1H), 9.46 (d, $J = 7.8$ Hz, 1H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 13.9, 23.3, 25.4, 32.3, 36.4, 39.3, 55.8, 61.3, 61.5, 68.0, 74.0, 135.5, 152.9, 170.5, 170.6, 193.5.

Synthesis of Enone (1b).

To a suspension of NaH (280 mg, 11.1 mmol, 1.1 equiv, 95% Aldrich) in 50 mL of DMF/toluene (1:1) was added diethyl allyl malonate (2.0 mL, 10.1 mmol, 1.0 equiv) drop wise via syringe under argon at room temperature. After stirring for 20 minutes, 2-bromomethyl-tetrahydropyran (1.5 mL, 11.1 mmol, 1.1 equiv) was added via syringe in one portion. After stirring overnight at 95 °C, the reaction was quenched with 20 mL

water and 100 mL of Et₂O and 100 mL of Hexanes were added. The layers were separated and the organic layer was washed with water (3 X 10 mL), brine (20 mL), dried over Sodium Sulfate, and concentrated *in vacuo*. Purification of the crude oil via flash chromatography (Hex:EtOAc = 30:1 then 10:1) gave **S4** as a colorless oil (1.82 g, 61% yield): IR 2937, 2848, 1733, 1201, 1093, 1050 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.24 (t, *J*_{av} = 6.4 Hz, 6H), 1.29-1.36 (m, 1H), 1.41-1.51 (m, 4H), 1.74-1.80 (m, 2H), 1.94-2.09 (m, 2H), 2.64-2.80 (m, 2H), 3.82 (dd, *J* = 11.1, 2.1 Hz, 1H), 4.10-4.21 (m, 4H), 5.06-5.11 (m, 2H), 5.61-5.70 (m, 1H); ¹³C NMR (CDCl₃, 75 MHz) δ 14.0, 23.5, 25.6, 32.3, 37.6, 38.9, 55.7, 60.9, 61.1, 68.0, 74.0, 118.7, 132.8, 171.3; MS (LR-APCI); calcd for C₁₆H₂₇O₅ 299.19, measured 299.36.

In a 250 mL round bottom flask was placed **S3** (1.5 g, 5.0 mmol) and 150 mL of CH₂Cl₂. The solution was cooled to -78 °C and ozone was bubbled through the solution until a blue color appeared. Air was passed through the solution to remove the excess ozone and then triphenyl phosphine (2.8 g, 10.1 mmol, 2.1 equiv) was added. After stirring overnight at room temperature, the solvent was removed *in vacuo*. Purification of the crude residue via flash chromatography (Hex:EtOAc = 10:1 then 5:1) gave **S4** as a clear oil (1.32 g, 87% yield): ¹H NMR (CDCl₃, 300 MHz) δ 1.21-1.36 (m, 7H), 1.47-1.54 (m, 4H), 1.8 (bs, 1H), 2.06-2.18 (m, 2H), 3.11 (q, *J* = 17.8 Hz, 2H), 3.20-3.34 (m, 2H), 3.93 (bd, *J* = 12.6 Hz, 1H), 4.19 (pentet, *J* = 7.0 Hz, 4H), 9.68 (s, 1H); ¹³C NMR (CDCl₃, 75 MHz) δ 13.8, 23.3, 25.5, 32.3, 39.8, 46.5, 53.2, 61.5, 61.6, 67.8, 74.2, 170.4, 170.5, 199.0; MS (LR-APCI); calcd for C₁₅H₂₅O₆ 301.17, measured 301.28.

To a 50 mL round bottom flask was placed **S4** (770 mg, 3.57 mmol), 20 mL of CH₂Cl₂, and 1-triphenylphosphoranylidene-2-propanone (1.64 g, 5.15 mmol, 1.8 equiv). The reaction was stirred for 3 days at ambient temperature under argon and then concentrated *in vacuo*. Purification of the crude material via flash chromatography (Hex:EtOAc = 10:1 to 5:1) gave **1b** (470 mg, 53% yield) as a colorless oil. ¹H NMR (CDCl₃, 400 MHz) δ 1.20-1.28 (m, 6H), 1.29-1.33 (m, 1H), 1.40-1.49 (m, 4H), 1.77-1.79 (m, 1H), 1.96 (dd, *J* = 14.8, 2.0 Hz, 1H), 2.07 (dd, *J* = 14.9, 9.6 Hz, 1H), 2.20 (s, 3H), 2.79 (dd, *J* = 14.6, 8.0 Hz, 1H), 2.91 (dd, *J* = 14.5, 7.1 Hz, 1H), 3.22-3.31 (m, 2H), 3.79-3.83 (m, 1H), 4.11-4.19 (m, 4H), 6.04 (d, *J* = 15.9 Hz, 1H), 6.66 (dt, *J*₁ = 15.9; *J*_{av2} = 7.8 Hz, 1H); ¹³C NMR (100 MHz) δ 14.1, 14.2, 23.6, 25.7, 26.8, 32.5, 36.5, 39.5, 55.9, 61.2, 61.4, 68.0, 74.0, 134.0, 142.4, 170.3, 170.4, 197.7.

Synthesis of Enone (1c).

To a 50 mL round bottom flask was placed **1a** (1.12 g, 3.46 mmol) and 10 mL of THF under argon. The solution was cooled to -78 °C and then phenyl magnesium bromide (1.25 mL, 3.75 mmol, 1.08 equiv,

Synthesis of malonate 3.

Synthesis of α -, β -Unsaturated Malonate (5).

To a 250 mL round bottom flask was placed **S6** (1.2 g, 5.87 mmol), 150 mL of acetonitrile and NaHCO_3 (1.5 g, 17.6 mmol, 3.0 equiv). The solution was stirred vigorously for 15 minutes and then cooled to 0 °C. Iodine (4.5 g, 17.6 mmol, 3.0 equiv) was added and the reaction was gradually allowed to warm to room temperature. After 2 hours, the reaction was quenched by the addition of saturated Na_2SO_3 . The majority of acetonitrile was removed *in vacuo*. 100 mL of ether was added and the layers separated. The aqueous layer was extracted with ether (2 X 25 mL). The combined organic layers were washed with brine, dried over Na_2SO_4 and concentrated *in vacuo*. The crude material was passed through a short plug of silica gel (Hex:EtOAc = 10:1) to yield the iodide **S6** as a mixture of diastereomers in quantitative yield.

In a 100 mL round bottom flask was placed NaH (421 mg, 17.5 mmol, 3 equiv, 95%) and 60 mL Toluene/DMF (1:1). Dimethyl malonate (2.0 mL, 17.5 mmol, 3 equiv) was added dropwise via syringe under argon. After stirring for 25 minutes, **S6** (1.93 g, 5.84 mmol) in 8 mL of toluene was added via syringe. The reaction was heated to 95 °C and stirred overnight. The reaction was quenched by the addition of 10 mL of water. 150 mL of ether and 25 mL of hexanes was added and the layers separated. The organic layer was washed with water (4 X 10 mL) and brine, dried over MgSO_4 , and concentrated *in vacuo*. Purification of the crude material via flash chromatography (Hex:EtOAc = 10:1 to 8:1) gave the *trans*-diastereomer **S7** (960 mg, 51% yield, slightly higher R_f than the *trans*-diastereomer). ^1H NMR CDCl_3 , 300 MHz) δ 1.17-1.28 (m, 2H), 1.41-1.70 (m, 4H), 1.75-1.82 (m, 2H), 2.02-2.12 (m, 2H), 2.60-2.68 (m, 1H), 2.72-2.77 (m, 1H), 3.17-3.26 (m, 2H), 3.72 (s, 3H), 3.75 (s, 3H), 3.76-3.81 (m, 1H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 23.4, 31.4, 31.5, 31.6, 35.3, 38.0, 52.4, 74.9, 125.6, 128.2, 128.4, 142.4, 170.0, 170.1.

To a solution of **S7** (940 mg, 2.81 mmol) in 30 mL of DMF/toluene (1:1) under argon was added NaH (78 mg, 3.09 mmol, 1.1 equiv, 95%) in one portion under argon. After stirring 25 minutes, allyl bromide (0.7 mL, 8.43 mmol, 3.0 equiv) was added and the reaction stirred for 3 hours at room temperature. The reaction was quenched by the addition of 5 mL of water. 100 mL of ether was added and the layers separated. The organic layer was washed with water (3 X 5 mL) and brine, dried over MgSO_4 , and concentrated *in vacuo*. The crude residue was placed in a 200 mL round bottom flask, and 50 mL ether and 75 mL water was added. To the vigorously stirred biphasic mixture was added OsO_4 (0.54 mL, 0.084 mmol, 0.03 equiv, 4%/wt in water). After 15 minutes, NaIO_4 (2.4 g, 11.2 mmol, 4.0 equiv) was added in one portion. After 48 hours, 50 mL of ether was added and the layers separated. The aqueous

layer was extracted with EtOAc (1 X 25 mL). The organic layers were combined and washed with 4 M NaOH (4 X 10 mL) and brine, dried over MgSO₄, and concentrated *in vacuo* to yield a crude aldehyde (crude weight 570 mg, 1.52 mmol), which was placed in an 8 mL vial and 0.5 mL of DMSO, and L-proline (53 mg, 0.46 mmol, 0.3 equiv) was added. The suspension was stirred for 15 minutes and then dimethyl malonate (0.35 mL, 3.04 mmol, 2.0 equivalents) was added. After approximately 19 hours (reaction monitored via ¹H NMR), 100 mL of EtOAc was added. The organic layer was washed with water (4 X 5 mL) and brine, dried over MgSO₄, and concentrated *in vacuo*.

Purification of the crude material via flash chromatography (Hex:EtOAc = 5:1) gave **5** as a colorless oil (450 mg, 32 % yield for three steps): ¹H NMR (CDCl₃, 400 MHz) δ 1.16-1.29 (m, 2H), 1.42-1.53 (m, 3H), 1.62-1.75 (m, 2H), 1.76-1.81 (m, 1H), 2.05 (dd, J = 15.0, 2.3 Hz, 1H), 2.29 (dd, J = 15.0, 10.5 Hz, 1H), 2.54-2.61 (m, 1H), 2.68-2.76 (m, 1H), 2.97-3.12 (m, 2H), 3.16-3.22 (m, 2H), 3.33-3.39 (m, 1H), 3.69 (s, 3H), 3.72 (s, 3H), 3.76 (s, 3H), 3.79 (s, 3H), 7.02 (dd, J = 8.7, 6.8 Hz, 1H), 7.14-7.28 (m, 5H); ¹³C NMR (75 MHz) δ 23.6, 31.1, 31.6, 32.1, 33.0, 38.1, 39.2, 52.3, 52.4, 52.5, 52.7, 55.4, 73.5, 77.1, 125.4, 128.0, 128.1, 129.7, 142.2, 144.2, 163.5, 165.0, 170.5, 170.6.

Synthesis of α-, β-Unsaturated Malonate (**7**).

In a 100 mL round bottom flask was placed **S8** (2.6 g, 16.6 mmol), and 60 mL of CH₂Cl₂ under argon. The solution was cooled in an ice/acetone bath and then TiCl₄ (2.7 mL, 25.0 mmol, 1.5 equiv) was added dropwise via syringe. After 30 minutes, the reaction was poured in to a 500 mL separatory funnel containing saturated bicarbonate. 300 mL of EtOAc was added and the layers separated. The organic layer was washed with brine, dried over MgSO₄, and concentrated *in vacuo*. Passage of the crude material through a short column of silica gel (Hex:EtOAc = 1:1) gave **S9** (2.8 g, 14.5 mmol, 86% yield) as a colorless oil, which was placed in to a 100 mL round bottom flask and dissolved in 20 mL HMPA. NaBH₄ (2.2 g, 58.1 mmol, 4.0 equiv) was added to the solution and the reaction heated to 95 °C for 24 hours. The reaction was allowed to cool to ambient temperature and poured into a 500 mL separatory funnel containing water. 350 mL of EtOAc was added and 5% HCl was added to dissolve any precipitates. The layers separated and the organic layer was washed with water (3 X 15 mL), brine, dried over MgSO₄, and concentrated *in vacuo*. Purification of the crude oil via flash chromatography (Hex:EtOAc = 2:1 then 1:1) gave **S10** (1.5 g, 65% yield): IR 3386(br), 2935, 2859, 1440, 1087, 1048; ¹H NMR (CDCl₃, 300 MHz) δ 1.19-1.29 (m, 1H), 1.31-1.69 (m, 2H), 1.58-1.82 (m, 2H), 3.21-3.26 (m, 1H), 3.35-3.44 (m, 1H), 3.62 (t, *J*_{av} = 6.3 Hz, 2H), 3.92-4.10

(m, 1H).

To a 100 mL round bottom flask was placed 30 mL of CH₂Cl₂ and oxalyl chloride (7.1 mL, 14.2 mmol, 1.5 equiv, 2.0 M in CH₂Cl₂) under argon. The solution was cooled to -78 °C and DMSO (1.6 mL, 21.8 mmol, 2.3 equiv) was added drop wise via syringe over 5 minutes. The reaction was stirred for 15 minutes and then **S10** (1.5g, 9.48 mmol) in 10 mL of CH₂Cl₂ was added. After 15 minutes, triethyl amine (6.3 mL, 47.4 mmol, 5.0 equiv) was added and the reaction was allowed to gradually warm to ambient temperature. Upon completion the majority of CH₂Cl₂ was removed, ether was added, and the reaction filtered through a pad of celite and concentrated *in vacuo*. Purification of the crude residue via flash chromatography (Hex:EtOAc = 10:1 then 7:1) gave **S11** (1.1 g, 74% yield): IR 2936, 2843, 1725, 1441, 1091, 1048; ¹H NMR (CDCl₃, 300 MHz) δ 1.19-1.33 (m, 1H), 1.39-1.86 (m, 9H), 2.41-2.46 (m, 2H), 3.18-3.29 (m, 1H), 3.34-3.42 (m, 1H), 3.92-3.97 (m, 1H), 9.73 (t, *J* 1.7 Hz, 1H); ¹H NMR (CDCl₃, 75 MHz) δ 18.3, 23.5, 26.1, 31.9, 35.8, 43.8, 68.4, 202.6.

7 was prepared in a similar manner as **3** starting from **S11** (1.0 g, 6.4 mmol). 680 mg (39% yield) of **7** were obtained after purification via flash chromatography (Hex:EtOAc = 6:1): IR 2936, 2845, 1732, 1438, 1372, 1262, 1225, 1090, 1063 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.20-1.27 (m, 1H), 1.36-1.64 (m, 8H), 1.75-1.80 (m, 1H), 2.28 (q, *J*_{av} = 7.4 Hz, 2H), 3.17-3.20 (m, 1H), 3.31-3.40 (m, 1H), 3.74 (s, 3H), 3.78 (m, 3H), 3.92 (bd, 1H), 7.00 (t, *J* = 7.8 Hz, 1 H); ¹³C NMR (CDCl₃, 75 MHz) δ 23.5, 24.2, 26.1, 29.7, 31.9, 35.9, 52.1, 52.2, 68.4, 77.2, 127.9, 150.3, 164.3, 165.8.

Synthesis of α-, β-Unsaturated Malonate (**9**).

S12 was prepared in analogous manner as **S1**; 2-Bromomethyl-tetrahydrofuran (13 mL, 114 mmol, 1.0 equiv), NaH (5.77g, 228 mmol, 2.0 equiv, 95%), diethyl malonate (34.7 mL, 228 mmol, 2.0 equiv). Vacuum distillation (~ 1 mmHg) of the residual oil through a Vigreux column (10 cm) gave **S12** as a colorless oil (20.7 g, 74% yield, bp 104-108 °C; ~ 1 mmHg): IR 2980, 2873, 1750, 1732, 1370, 1267, 1242, 1155, 1063, 1031 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.24-1.29 (m, 6H), 1.45-1.56 (m, 1H), 1.82-1.90 (m, 2H), 1.94-2.18 (m, 3H), 3.55 (dd, *J* = 8.6, 6.0 Hz, 1H), 3.69 (q, *J*_{av} = 7.3 Hz, 1H), 3.79 (t, *J*_{av} = 6.7 Hz, 1H), 3.84-3.91 (m, 2H), 4.1-4.27 (m, 4H); ¹³C NMR

(CDCl₃, 100 MHz) δ 14.0, 25.5, 31.3, 34.5, 49.4, 61.3, 67.6, 76.4, 169.3, 169.5.

To a solution of **S12** (1.0g, 4.09 mmol) in 50 mL of DMF/toluene under argon was added NaH (130 mg, 4.90 mmol, 1.2 equiv, 95%) portion wise. After stirring 15 minutes, allyl bromide (860 μ L, 10.2 mmol, 2.5 equiv) was added and the reaction stirred for 3 hours at room temperature. The reaction was quenched by the addition of 20 mL of water. 100 mL of ether and 25 mL of hexanes was added and the layers separated. The organic layer was washed with water (4 X 10 mL) and brine, dried over MgSO₄, and concentrated *in vacuo*. The resulting crude oil was dissolved in 100 mL of CH₂Cl₂ and the solution cooled to -78 °C. Ozone was bubbled through the solution until a blue color appeared. Air was passed through the solution to remove the excess ozone. Triphenyl phosphine was added (1.3g, 4.91 mmol, 1.2 equiv) After stirring for 24 hours at room temperature, the solvent was removed *in vacuo*. Purification of the crude residue via flash chromatography (Hex:EtOAc = 3:1 then 2:1) gave **S13** as a clear oil (500 mg, 43% yield): IR 2980, 2875, 1731, 1446, 1367, 1288, 1193, 1096, 1020, cm⁻¹; ¹H NMR (500 MHz) δ 1.25 (t, *J* = 7.1 Hz, 6H), 1.46-1.53 (m, 1H), 1.77-1.91 (m, 2H), 2.20 (dd, *J* = 14.7, 10.0 Hz, 1H), 2.28 (dd, *J* = 14.7, 2.3 Hz, 1H), 3.12 (d, *J* = 18.0 Hz, 1H) 3.30 (d, *J* = 18.0 Hz, 1H) 3.65 (q, *J*_{av} = 7.3 Hz, 1H), 3.73 (q, *J*_{av} = 7.4 Hz, 1H), 3.84-3.89 (m, 1H), 4.15-4.23 (m, 4H), 9.73 (s, 1H); ¹³C NMR (125 MHz) δ 13.9, 25.2, 32.5, 38.8, 46.2, 53.9, 61.7, 61.8, 67.7, 75.2, 170.4, 170.5, 199.4.

9 was prepared in a similar manner as **3** starting from **S13** (493 mg, 1.64 mmol). 472 mg (72% yield) of **9** were obtained after purification via flash chromatography (Hex:EtOAc = 10:1 then 5:1): ¹H NMR (CDCl₃, 400 MHz) δ 1.16-1.21 (m, 6H), 1.41-1.46 (m, 1H), 1.72-1.83 (m, 2H), 1.91-1.98 (m, 1H), 2.02-2.14 (m, 2H), 2.92-3.05 (m, 2H), 3.57-3.62 (m, 1H), 3.65-3.71 (m, 1H), 3.67 (s, 3H), 3.81 (s, 3H), 3.82-3.84 (s, 3H), 4.10, 4.16 (m, 4H), 6.93 (t, *J* = 7.1 Hz, 1H); ¹³C NMR (100 MHz) δ 14.0, 25.4, 32.4, 33.0, 38.8, 52.2, 52.3, 55.8, 61.4, 61.8, 67.6, 74.6, 130.5, 144.4, 163.5, 164.9, 170.0, 170.1.

Synthesis of Enal (11).

To a solution of **S12** (3.15 g, 12.9 mmol) in 100 mL of DMF/toluene under argon was added NaH (130 mg, 4.90 mmol, 1.2 equiv, 95%) portion wise. After stirring 20 minutes, the allylic bromide **S2** (2.84 g, 14.9 mmol, 1.15 equiv) was added and the reaction stirred for 3 hours at room temperature. The reaction was quenched by the addition of 20

mL of water. 200 mL of ether and 100 mL of hexanes was added and the layers separated. The organic layer was washed with water (4 X 10 mL) and brine, dried over MgSO₄, and concentrated *in vacuo*. The resulting crude oil was dissolved in 125 mL of absolute ethanol and a catalytic amount of *p*-toluenesulfonic acid monohydrate (c.a 100 mg) was added. The resulting solution was refluxed for 36 hours and then the solvent was removed *in vacuo*. The crude residue was filtered through a short plug of silica gel (Hex:EtOAc = 2:1) to remove the residual acid. Swern oxidation of the resulting alcohol and purification via flash chromatography (Hex:EtOAc = 2:1) gave **11** as a colorless oil (3.0 g, 74 % yield for three steps). A *cis*- : *trans*- (9:1) mixture was obtained. It was found that the amount of the *trans*-isomer was increased by standing in CDCl₃. Spectroscopic data for the *cis*-isomer is given: IR 2980, 1732, 1682, 1447, 1290, 1237, 1190, 1130, 1085, 1018 cm⁻¹; ¹H NMR (CDCl₃, 500 MHz) δ 1.22 (t, *J* = 7.1 Hz, 6H), 1.44-1.51 (m, 1H), 1.75-1.85 (m, 2H), 1.96-2.02 (m, 1H), 2.08-2.17 (m, 2H), 3.26 (dd, *J* = 15.0, 8.3 Hz, 1H), 3.42 (dd, *J* = 15.0, 8.3 Hz, 1H), 3.62-3.66 (m, 1H), 3.69-3.75 (m, 1H), 3.81-3.83 (m, 1H), 4.15-4.19 (m, 4H), 5.97-6.06 (m, 1H), 6.49-6.55 (m, 1H), 10.04 (d, *J* = 8.1 Hz, 1H).

Synthesis of Enal **13**.

S15 was prepared in analogous manner as **S1**; **S14** (8.75g, 52.6 mmol), NaH (2.66g, 105.3 g, 2.0 equiv, 95 %), diethyl malonate (16.6 mL, 105.3 mmol, 2.0 equiv). Vacuum distillation (~.5 mmHg) of the crude material through a Vigreux column (10 cm) gave **S15** as a colorless oil (9.1 g, 75% yield, bp 75 °C; ~.5 mmHg): ¹H NMR (CDCl₃, 400 MHz) δ 1.25-1.30 (m, 6H), 1.62-1.71 (m, 1H), 2.07-2.16 (m, 1H), 2.84-2.93 (m, 1H), 3.31 (d, *J* = 10.4 Hz, 1H), 3.51 (dd, *J* = 9.0, 6.7 Hz, 1H), 3.73-3.79 (m, 1H), 3.84-3.90 (m, 1H), 3.99 (dd, *J* = 9.0, 7.4 Hz, 1H), 4.16-4.25 (m, 4H); ¹³C NMR (CDCl₃, 100 MHz) δ 14.1, 14.2, 30.3, 38.6, 55.2, 61.4, 61.5, 67.6, 71.4, 168.0, 168.1.

13 was prepared in a similar manner as **1a** starting from **S15** (2.3 g, 9.97 mmol). 1.9 g (64% yield for three steps) of **13** were obtained after purification via flash chromatography (Hex:EtOAc = 1:1): IR 2982, 1726, 1693, 1251, 1191 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.21-1.27 (m, 6H), 1.74-1.86 (m, 1H), 1.94-2.05 (m, 1H), 2.76-2.83 (m, 1H), 2.86 (d, *J* = 7.4 Hz, 2H), 3.62 (q, *J*_{av} = 8.0 Hz, 1H), 3.76-3.88 (m, 3H), 4.14-4.22 (m, 4H), 6.11 (ddm, *J* = 15.5, 7.8 Hz, 1H), 6.74 (dt, *J* = 15.5, 7.4 Hz, 1H), 9.45 (d, *J* = 7.8 Hz, 1H). ¹³C NMR (75 MHz) δ 13.9, 27.6, 36.8, 42.6, 59.1, 61.6, 61.7, 67.8, 69.3, 135.5, 151.9, 169.5, 169.8, 193.2; MS (LR-APCI): calculated for C₁₅H₂₃O₆ 299.15, measured 299.01.

Synthesis of Enal (15).

To a 250 mL round bottom flask was added 3-hydroxy-pyrrolidine hydrochloride (5.6g, 45.3 mmol) 120 mL of ether, and 60 mL of water. The biphasic solution was stirred vigorously and Na_2CO_3 (14.4g, 136 mmol, 3 equiv) was added. After 20 minutes, methyl chloroformate (5.6 mL, 72.5 mmol, 1.6 equiv) was added. The reaction was stirred overnight and then 15 mL of 1M HCl was added. The layers were separated and the aqueous layer was extracted with EtOAc (2 X 200 mL). The combined organic layer was dried with MgSO_4 and concentrated *in vacuo*. The resulting crude oil (3.15g, 21.7 mmol, 48% yield) was dissolved in 100 mL of CH_2Cl_2 and triethyl amine (3.3 mL, 23.9 mol, 1.1 equiv) was added. The solution was cooled to 0°C under argon and methane sulfonyl chloride (1.85 mL, 23.9 mmol, 1.1 equiv) was added via syringe. The reaction was allowed to gradually warm to ambient temperature and stirred overnight. 60 mL of water was added and the layers separated. The aqueous later was extracted with CH_2Cl_2 (2 X 100 mL). The combined organic layer was dried with MgSO_4 and concentrated *in vacuo*. Purification of the crude oil via flash chromatography (100% EtOAc) gave **S16** (4.6g, 95% yield) as a colorless oil: ^1H NMR (300 MHz) δ 2.12-2.18 (m, 1H), 2.23-2.30 (m, 1H), 3.05 (s, 3H), 3.48-3.63 (m, 3H), 3.71 (s, 3H), 3.71-3.78 (m, 1H), 5.27 (bs, 1H).

To a 150 mL round bottom flask containing 80 mL of DMF/toluene (1:1) and diethyl malonate (6.1 mL, 39.9 mmol, 2.0 equiv) was added NaH (1.0 g, 39.9 mmol, 2.0 equiv, 95%) portion wise. After stirring for 20 minutes at room temperature under argon, **S16** (4.45 g, 19.9 mmol, 1.0 equiv) in 15 mL of toluene was added via syringe in one portion. The resulting reaction mixture was heated to 95°C overnight and

quenched in a 1000 mL separatory funnel containing 100 mL water. 300 mL of ether and 100 mL hexanes was added and the layers separated. The organic layer was washed with water (1 X 40 mL, 3 X 20 mL) and brine, dried with MgSO_4 and concentrated *in vacuo*. Purification of the crude oil via flash chromatography (Hex:EtOAc = 3:1) gave **S17** (3.28g, 55% yield) as a colorless oil: IR 2983, 2878, 1732, 1708, 1370, 1452, 1392, 1177, 1029 cm^{-1} ; ^1H NMR (300 MHz) δ 1.22-1.28, 1.61-1.68 (m, 1H), 2.07 (bs, 1H), 2.75-2.83 (m, 1H), 3.05 (q, $J_{av} = 10.6$ Hz, 1H), 3.23-3.33 (m, 1H), 3.44-3.56 (m, 1H), 3.65 (s, 3H), 3.68-3.71 (m, 1H), 4.13-4.22 (m, 4H).

15 was prepared in a similar manner as **1a** starting from **S17** (1.25 g,

4.15 mmol). 1.2 g (84% yield for three steps) of **15** were obtained after purification via flash chromatography (Hex:EtOAc = 3:2 then 1:2): IR 1726, 1698, 1453, 1392, 1191, 1138 cm^{-1} ; ^1H NMR (DMSO- d_6 , 360K, 300 MHz) δ 1.20 (t, J = 7.1 Hz, 3H), 1.21 (t, J = 7.1 Hz, 3H), 1.71-1.84 (m, 1H), 2.00-2.10 (m, 1H), 2.73-2.85 (m, 1H), 2.90 (dd, J = 12.8, 1.2 Hz), 3.17-3.29 (m, 2H), 3.38-3.45 (m, 1H), 3.54-3.61 (m, 4H), 4.13-4.22 (m, 4H), 6.17 (dd, J = 15.5, 7.6 Hz, 1H), 6.89 (dd, J = 15.5, 7.4 Hz, 1H), 9.50 (d, J = 7.6 Hz, 1H); ^{13}C NMR (DMSO- d_6 , 360K, 75 MHz) δ 13.2, 26.0, 35.7, 41.0, 44.6, 46.7, 51.3, 58.2, 60.9, 134.8, 151.4, 154.0, 168.7, 168.8, 193.2.

Synthesis of enone (**17**).

To a 25 mL round bottom flask was placed **S18**¹ (500 mg, 3.0 mmol), 10 mL of CH_2Cl_2 , and 1-triphenylphosphoranylidene-2-propanone (1.7 g, 5.4 mmol, 1.8 equiv). The reaction was stirred for 24 hours at ambient temperature (reaction monitored via ^1H NMR) and the concentrated *in vacuo*. Ether was added and the reaction filtered and concentrated. Purification of the crude material via flash chromatography (Hex:EtOAc = 6:1 then 3:1) gave **17** (500 mg, 80% yield) as a colorless oil. ^1H NMR (CDCl_3 , 300 MHz) δ 2.34 (s, 3H), 2.62 (qd, J = 6.6, 1.4 Hz, 2H), 3.69 (t, J = 6.3 Hz), 4.61 (s, 2H), 6.22 (d, J = 16.0 Hz), 6.89 (dt, J = 16.0, 6.8 Hz, 1H), 7.34-7.43 (m, 5H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 26.7, 32.8, 68.2, 73.0, 127.6, 128.3, 132.6, 138.0, 144.7, 198.3.

Synthesis of α -, β -Unsaturated Malonate (**19**).

To a solution of **S19** (1.9 g, 13.5 mmol) in a 150 mL round bottom flask at 0 $^\circ\text{C}$ was added 4-methoxyphenylmagnesium bromide (54.2 mL, 27.1 mmol, 2.0 equiv, 2.0 M THF) via syringe. The cooling bath was removed and reaction stirred for 1.5 hours and then quenched with saturated NH_4Cl , and concentrated to remove the majority of the THF. Ether was added and the solvent decanted from the precipitated. The organic layer was washed with 35 mL water and the aqueous layer extracted with 25 mL EtOAc. The organic layers were combined, washed with brine, dried with Na_2SO_4 , and

¹ Prepared from Swern oxidation of commercially available 3-Benzyloxy-propan-1-ol.

concentrated *in vacuo*. Purification of the crude oil via flash chromatography (Hex/EtOAc = 15:1) gave **S20** (2.38g, 75% yield) as a colorless oil. ^1H NMR (300 MHz) δ 0.72 (s, 3H), 0.79 (s, 3H), 1.54 (s, 3H), 1.72 (s, 1H), 1.87 (d, J = 6.6 Hz, 2H), 1.89-1.99 (m, 2H), 3.78 (s, 3H), 4.91-5.00 (m, 2H), 5.72-5.82 (m, 2H), 6.83 (d, J = 8.3 Hz, 2H), 7.33 (d, J = 8.3 Hz, 2H).

To a 100 mL round bottom flask was placed **S20** (2.35g, 10.6 mmol) and 50 mL of CH_2Cl_2 . Triethylsilane (4.1 mL, 25.8 mmol, 5.0 equiv) was added and the solution cooled to -78°C . $\text{BF}_3\cdot\text{Et}_2\text{O}$ (1.3 mL, 10.3 mmol, 2.0 equiv) was added drop wise via syringe over a 5 minute period. The reaction was stirred for 5 hours while not allowing the cooling bath to surpass -10°C , and then poured into a separatory funnel containing 50 mL of saturated bicarbonate. The layers were separated and the aqueous layer extracted with CH_2Cl_2 (2 X 30 mL). The organic layers were combined, washed with brine, dried over MgSO_4 , and concentrated *in vacuo*. The crude oil was placed in a 200 mL round bottom flask and 75 mL ether, and 100 mL water was added. To the vigorously stirred biphasic mixture was added OsO_4 (2.1 mL, 0.31 mmol, 0.03 equiv, 4%/wt in water). After 15 minutes, NaIO_4 (9.01 g, 42.4 mmol, 4.0 equiv) was added in one portion. After 24 hours, 50 mL of ether was added and the layers separated. The aqueous layer was extracted with EtOAc (2 X 25 mL). The organic layers were combined and washed with 4 M NaOH (4 X 10 mL) and brine, dried over MgSO_4 , and concentrated *in vacuo*. Purification of the resulting crude oil via flash chromatography (Hex/EtOAc = 6:1) give **S21** (1.17 g, 47% yield for two steps) as a colorless oil; IR 2958, 1719, 1612, 1512, 1466, 1247, 1178, 1036, 830; ^1H NMR (CDCl_3 , 500 MHz) δ 0.95 (s, 6H), 1.21 (d, J = 7.0 Hz, 3H), 1.58 (dd, J = 14.3, 3.8 Hz, 1H), 1.86 (dd, J = 14.2, 9.0 Hz, 1H), 2.12 (d, J = 2.8 Hz, 1H), 2.82 (m, 1H), 3.77 (s, 3H), 6.82 (d, J = 8.5 Hz, 2H), 7.10 (d, J = 8.5 Hz, 2H), 9.68 (t, J = 2.8 Hz, 1H); ^{13}C NMR (CDCl_3 , 133 MHz) δ 26.0, 28.0, 28.3, 34.0, 35.6, 50.4, 55.0, 55.1, 113.8, 127.8, 140.4, 157.8, 203.4.

19 was prepared in a similar manner as **3** starting from **S21** (730 mg, 3.11 mmol). 920 mg (85% yield) of **19** were obtained after purification via flash chromatography (Hex:EtOAc = 10:1): IR 2956, 1732, 1644, 1612, 1513, 1437, 1248, 1060, 830 cm^{-1} ; ^1H NMR (CDCl_3 , 400 MHz) δ 0.80 (s, 3H), 0.83 (s, 3H), 1.19 (d, J = 7.0 Hz, 3H), 1.51 (dd, J = 14.2, 4.0 Hz, 1H), 1.73 (dd, J = 14.2, 8.8 Hz, 1H), 2.05-2.18 (m, 2H), 2.76-2.80 (m, 1H), 6.80-6.83 (m, 2H), 7.03 (t, J = 8.0 Hz, 1H), 7.08-7.12 (m, 2H); ^{13}C NMR (CDCl_3 , 133 MHz) δ 26.3, 27.8, 35.0, 35.7, 42.4, 50.3, 52.2, 52.4, 55.2, 113.6, 127.6, 128.8, 140.5, 147.4, 157.3, 163.9, 165.7.

Synthesis of α -, β -Unsaturated Malonate **21**.

In a 50 mL round bottom flask was placed 2-bromothiophene (0.53 mL, 5.5 mmol, 1.1 equiv) and 25 mL THF. The solution was cooled to -78 °C and *n*-BuLi (3.4 mL, 5.5 mmol, 1.1 equiv, 1.6M in hexanes) was added via syringe. After 25 minutes, **S19** (700 mg, 5.0 mmol) in 5 mL of THF was added via syringe. After 1 hour, the reaction was quenched by the addition of saturated NH₄Cl. The majority of THF was removed and 100 mL of ether was added. The layers were separated and the aqueous layer was extracted with 25 mL of ether. The organic layers were combined and washed with brine, dried over MgSO₄ and concentrated *in vacuo* to yield **S22**. Crude **S22** was placed in a 100 mL RBF, dissolved in 30 mL of CH₂Cl₂ and triethyl silane (6.4 mL, 40.0 mmol, 8.0 equiv) was added and the solution cooled to -78 °C. Boron trifluoride diethyl etherate (1.3 mL, 10.0 mmol, 2.0 equiv) was added dropwise via syringe over 5 minutes. After 1 hour, the reaction was poured into a separatory funnel containing 30 mL of saturated bicarbonate. The layers were separated and the aqueous layer extracted with CH₂Cl₂ (2 X 30 mL). The organic layers were combined, washed with brine, dried over MgSO₄, and concentrated *in vacuo*. The crude oil was placed in a 200 mL round bottom flask and 50 mL ether, and 50 mL water was added. To the vigorously stirred biphasic mixture was added OsO₄ (1.7 mL, 0.13 mmol, 0.03 equiv, 2.5%/wt in 2-methyl-2-propanol). After 15 minutes, NaIO₄ (2.9 g, 13.4 mmol, 4.0 equiv) was added in one portion. After 34 hours, 50 mL of ether was added and the layers separated. The aqueous layer was extracted with EtOAc (1 X 25 mL). The organic layers were combined and washed with 4 M NaOH (4 X 5 mL) and brine, dried over MgSO₄, and concentrated *in vacuo*. Purification of the resulting crude oil via flash chromatography (Hex/EtOAc = 6:1) give **S23** (420 mg, 40% yield for three steps) as a colorless oil; ¹H NMR (CDCl₃, 300 MHz) δ 1.04 (s, 3H), 1.34 (d, *J* = 6.8 Hz, 3H), 1.67 (dd, *J* = 14.2, 4.0 Hz, 1H), 1.92 (dd, *J* = 14.2, 8.3 Hz, 1H), 2.21 (d, *J* = 2.9 Hz, 2H), 3.19-3.25 (m, 1H), 6.79-6.80 (m, 1H), 6.87-6.90 (m, 1H), 7.09 (d, *J* = 5.0 Hz, 1H), 9.73 (t, *J* = 2.9 Hz).

21 was prepared in a similar manner as **3** starting from **S23** (400 mg, 1.9 mmol). 529 mg (86% yield) of **21** were obtained after purification via flash chromatography (Hex:EtOAc = 15:1); IR 2957, 1731, 1644, 1436, 1368, 1263, 1225, 1060, 696; ¹H NMR (CDCl₃, 300 MHz) δ 0.87 (s, 3H), 0.89 (s, 3H), 1.30 (d, *J* = 6.9 Hz, 3H), 1.57 (dd, *J* = 14.2, 4.2 Hz, 1H), 1.78 (dd, *J* = 14.2, 8.1 Hz, 1H), 2.19-2.15 (m, 1H), 3.11-3.19 (m, 1H), 3.77 (s, 3H), 3.80 (m, 3H), 6.77-6.78 (m, 1H), 6.85-6.88 (m, 1H), 7.03-7.09 (m, 2H); ¹³C NMR (CDCl₃, 133 MHz) δ 26.9, 27.2, 31.8, 34.8, 40.1, 51.4, 52.1,

52.2, 122.3, 122.4, 126.4, 129.1, 147.2, 147.7, 153.1, 164.1, 165.9.

III. General Procedure for Hydroalkylation.

Platinum(IV)chloride and scandium triflate were purchased from Strem and used as received. Boron trifluoride etherate was purchased from Aldrich and used as received. Older bottles of catalyst (> 1 year) could be employed with out a noticeable decrease in performance. All reactions were carried out in round bottom flasks from the drawer and were not dried prior to use. Reactions run at elevated temperature were carried out in sealed tubes. Solid catalysts were weighed out in air. Micro syringes were used for liquid catalysts. All reactions were run on 0.5 mmol or 0.25mmol scale at 0.025 M concentration of substrate. Reactions were monitored by TLC analysis using hexanes/ethyl acetate mixtures as the eluent (visualization using permanganate stain and/or ceric ammonium molybdate stain and/or UV light). The hydroarylation products typically have slightly higher R_f s than starting materials.

General procedure: In a 50 mL of round bottom flask was weighed 0.50 mmol of substrate. The Flask was capped with a septum and evacuated and filled with argon three times. 20 mL of CH_2Cl_2 was added via syringe. The septum was removed from the flask and the catalyst added to the solution. The Septa was put back on the flask and the reaction stirred for the appropriate time given in Table 1. Reactions were monitored by TLC analysis. After completion, the solvent was removed on a rotary evaporator and the crude residue purified via flash chromatography (yields given in Table 1).

The diastereomeric mixture could be separated via flash chromatography (Hex:EtOAc = 15:1). The *cis*-configuration (higher R_f) was determined to be the major diastereomer via X-Ray

crystallography. *Cis*-diastereomer: A white solid. IR 2939, 1732, 1446, 1257, 1232, 1189, 1133, 1082, 1049 cm^{-1} ; ^1H NMR (CDCl_3 , 500 MHz) δ 1.24 (t, $J = 7.1$ Hz, 3H), 1.29 (t, $J = 7.1$ Hz, 3H), 1.41-1.50 (m, 4H), 1.36-1.50 (m, 4H), 1.55-1.61 (m, 2H), 1.65-1.73 (m, 3H), 1.98 (td, $J = 12.6, 4.1$ Hz, 1H), 2.37 (qd, $J_{\text{lav}} = 13.1$; $J_2 = 3.3$ Hz, 1H), 2.51 (dm, $J = 13.2$ Hz, 1H), 3.16 (dd, $J = 13.7, 1.4$ Hz, 1H), 3.54-3.58 (m, 1H), 3.63 (qd, $J_{\text{lav}} = 9.4$; $J_{2\text{av}} = 2.6$ Hz, 1H), 4.07-4.22 (m, 3H), 4.30-4.37 (m, 1H), 9.80 (d, $J = 3.9$ Hz, 1H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 13.9, 18.9, 19.6, 25.7, 29.7, 33.6, 34.6, 52.0(q), 57.1, 61.1, 61.6, 61.7, 72.0(q), 170.5(q), 172.1(q), 206.2.

Trans-diastereomer: IR 2938, 1732, 1231, 1176, 1078, 1051 cm^{-1} ; ^1H NMR (CDCl_3 , 500 MHz) δ 1.22 (m, 6H), 1.47-1.68 (m, 6H), 1.78-1.82 (m, 2H), 2.07-2.10 (m, 1H), 2.16-2.21 (m, 1H), 2.37 (d, $J = 14.6$ Hz, 1H), 2.47 (d, $J = 14.5$ Hz, 1H), 2.69 (m, 1H), 3.53 (m, 1H), 3.66-3.71 (m, 1H), 4.11-4.24 (m, 4H), 9.88 (s, 1H);

A side product **S23** (baseline R_f in 3:1 Hex:EtOAc) was identified in the reaction of **1a**. The amount of **S23** was found to increase with increasing reaction time. For example reacting **1a** with 30

mol% Boron trifluoride etherate for 21 hours resulted in a decrease of yield of **2a** (81 %) with increased diastereoselectivity (dr = 5:1). Although other catalysts such as Sc(OTf)₃ and PtCl₄ are promote the hydroalkylation of **1a**, they were found to produce larger amounts of **S23**: IR 3461(br), 1732, 1666, 1636, 1447, 1368, 1253, 1179, 1086, 1028 cm⁻¹; ¹H NMR (CDCl₃, 400 MHz) δ 1.23 (t, J_{av} = 7.0 Hz, 6H), 1.59-1.64 (m, 2H), 1.66-1.71 (m, 2H), 2.12 (t, J_{av} = 6.5 Hz, 2H), 2.34 (t, J = 6.2 Hz, 2H), 2.60 (t, J_{av} = 7.5 Hz, 2H), 2.72 (s, 2H), 3.66 (t, J_{av} = 6.1 Hz, 2H), 4.14- 4.20 (apparent quartet, 4H); ¹³C NMR (100 MHz) δ 14.2, 19.9, 25.7, 26.8, 31.5, 32.4, 36.8, 53.1, 61.7, 62.4, 132.0, 156.0, 170.5, 189.5.

The diastereomeric mixture could be separated via flash chromatography (Hex:EtOAc = 9:1). The *cis*-configuration (higher R_f) was determined to be the major diastereomer by analogy to **1a** wherein the *cis*-configuration was the major product. Due to overlapping in the methylene region nOe experiments could not be used to determine the relative configuration. *Cis*-diastereomer: ¹H NMR (CDCl₃, 400 MHz) δ 1.20 (t, J = 7.1 Hz, 3H), 1.26 (t, J = 4.1 Hz, 3H), 1.34-1.61 (m, 9H), 2.13 (s, 3H), 2.13-2.17 (m, 1H), 2.41-2.51 (m, 2H), 3.13 (dd, J = 15.0, 1.7 Hz, 1H), 3.53-3.58 (m, 2H), 4.03-4.17 (m, 3H), 4.30-4.34 (m, 1H); ¹³C NMR (CDCl₃, 100 MHz) δ 13.9, 18.8, 21.5, 25.7, 29.3, 30.3, 33.8, 34.0, 52.1, 61.0, 61.5, 61.7, 62.0, 71.5, 170.6, 172.1, 212.4.

Trans-diastereomer: ¹H NMR (CDCl₃, 400 MHz) δ 1.21-1.26 (m, 6H), 1.29-1.36 (m, 1H), 1.40-1.78 (m, 7H), 2.03-2.07 (m, 1H), 2.16-2.25 (m, 1H), 2.19 (s, 3H), 2.45 (d, J = 14.4 Hz, 1H), 2.67 (d, J = 14.5 Hz, 1H), 2.88 (t, J = 5 Hz, 1H), 3.49-3.54 (m, 1H), 3.62-3.68 (m, 1H), 4.06-4.25 (m, 4H); ¹³C NMR (CDCl₃, 100 MHz) δ 13.9, 18.7, 20.8, 25.8, 27.0, 32.0, 32.3, 33.4, 52.6, 55.2, 61.0, 61.1, 61.4, 72.7, 171.3, 171.8, 210.2

The diastereomeric mixture could be separated via flash chromatography (Hex:EtOAc = 9:1). The *cis*-configuration (lower R_f) was determined to be the major diastereomer by analogy to **1a** wherein the *cis*-configuration was the major product. Due to overlapping in the methylene region nOe experiments could not be used to determine the relative configuration. *Cis*-diastereomer: ¹H NMR (CDCl₃, 400 MHz) δ 1.24 (t, J = 7.1 Hz, 3H), 1.28 (t, J = 7.1 Hz, 3H), 1.35-1.40 (m, 2H), 1.46-1.54 (m, 3H), 1.60-1.70 (m, 3H), 1.89 (d, J = 14.7 Hz, 1H), 2.42-2.50 (m, 2H), 3.19 (dd, J = 14.8, 1.2 Hz, 1H), 3.40-3.43 (m, 2H), 3.59-3.62 (m, 2H), 4.12-4.20 (m, 3H), 4.25-4.31 (m, 1H), 7.41-7.43 (m, 2H), 7.50-7.54 (m, 1H), 7.90-7.92 (m, 2H); ¹³C NMR (CDCl₃, 100 MHz) δ 14.2, 19.2, 22.5, 25.6, 30.1, 34.5, 35.0, 52.0, 52.8, 61.3, 61.5, 61.8, 72.9, 128.1, 128.3, 132.3, 138.7, 170.3, 172.2, 200.9.

Trans-diastereomer: ¹H NMR (CDCl₃, 400 MHz) δ 1.23 (t, J = 7.1 Hz, 3H), 1.27 (t, J = 7.1 Hz, 3H), 1.33-1.51 (m, 4H), 1.57-1.72 (m, 4H), 2.17-2.22 (m, 1H), 2.46-2.54 (m, 1H), 2.75 (s, 2H), 3.52-3.56 (m, 1H), 3.65-3.71 (m, 1H), 3.77-3.79 (m, 1H), 4.07-4.22 (m, 3H), 4.07-4.22 (m, 1H), 7.42-7.46 (m, 2H), 7.52-7.56 (m, 1H), 7.93-7.95 (m, 2H); ¹³C NMR (CDCl₃, 100 MHz) δ 14.2, 18.9, 21.9, 26.0, 26.4, 32.9, 33.9, 49.1, 52.5, 61.0, 61.1, 61.4, 73.1, 128.1, 128.4, 132.7, 137.2, 171.0, 171.8, 200.7.

A colorless oil (SiO₂, Hex:EtOAc = 2:1): ¹H NMR (CDCl₃, 400 MHz) δ 1.21 (t, J = 7.1 Hz, 3H), 1.26 (t, J = 7.1 Hz, 3H), 1.32-1.43 (m, 3H), 1.61-1.67 (m, 2H), 1.92-1.98 (m, 2H), 2.31-2.42 (m, 3H), 2.85 (td, J = 14.5, 3.5 Hz, 1H), 3.10 (dd, J = 15.5, 2.1 Hz, 1H), 3.45-3.49 (m, 1H), 3.58 (td, J_{av1} = 11.7, J_{av2} = 3.2 Hz, 1H), 3.67 (s, 3H), 3.72 (s, 3H), 4.04-4.17 (m, 3H), 4.25-4.33 (m, 1H); ¹³C NMR (CDCl₃, 100 MHz) δ 14.2, 19.2, 25.4, 26.4, 27.0, 29.6, 31.4, 51.9, 52.2, 61.2, 61.5, 61.8, 62.5, 74.9, 169.8, 169.9, 170.3, 171.6.

An inseparable mixture of diastereomers was obtained as a clear oil (SiO₂, Hex:EtOAc = 2:1): The diastereoselectivity was determined from the integration of the only two distinct resonances in the ¹H NMR spectrum of the mixture: ¹H NMR (CDCl₃, 500 MHz) δ 2.89 (td, J_1 = 14.5; J_{2av} = 2.6 Hz, major diastereomer), 3.01 (td, J = 14.3, 3.2 Hz, minor diastereomer); ¹³C NMR (CDCl₃, 133 MHz) δ 15.3, 19.2, 25.6, 26.3, 26.8, 27.4, 28.0, 29.3, 29.8, 30.7, 32.0, 32.3, 38.8, 39.1, 51.9, 52.2, 52.3, 52.4, 52.7, 52.9, 61.6(q), 62.6(q), 69.8, 70.2, 75.4(q), 76.1(q), 125.3, 125.4, 128.0, 128.1, 128.2, 142.4(q), 169.8(q), 170.1(q), 170.2(q), 170.5(q), 171.0(q), 172.0(q), 172.2 (q); MS (LR-APCI): calculated for C₂₆H₃₅O₉ 491.23, measured 491.36.

A colorless oil (SiO₂, Hex:EtOAc = 6:1): IR 2952, 2859, 1734, 1435, 1296, 1245, 1208, 1150, 1076, 1023 cm⁻¹; ¹H NMR (CDCl₃, 500 MHz) δ 1.08-1.23 (m, 1H), 1.37-1.40 (m, 2H), 1.56-1.73 (m, 4H), 1.91-2.06 (m, 4H), 2.37-2.43 (m, 2H), 3.51-3.56 (m, 1H), 3.62 (bd, 1H), 3.64 (s, 3H), 3.71 (s, 3H); ¹³C NMR (CDCl₃, 75 MHz) δ 18.7, 20.0, 22.1, 25.2, 25.5, 29.4, 29.6, 51.8, 51.9, 60.4 (q), 63.2 (q), 75.1, 170.5(q), 170.6(q); MS (LR-APCI): calculated for C₁₄H₂₃O₅ 271.15, measured 271.24.

A colorless oil (SiO₂, Hex:EtOAc = 2:1): ¹H NMR (CDCl₃, 400 MHz) δ 1.13 (t, J = 7.1 Hz, 3H), 1.18 (t, J = 7.1 Hz, 3H), 1.26 (td, J = 14.1, 3.6 Hz, 1H), 1.54-1.66 (m, 1H), 1.76-1.87 (m, 2H), 2.08 (dt, J = 14.4, 3.4 Hz), 2.34-2.39 (m, 3H), 2.57-2.62 (m, 1H), 2.71 (td, J = 14.3, 3.6 Hz, 1H), 3.46 (q, J_{av} = 7.5 Hz, 1H), 3.51-3.59 (m, 1H), 3.62 (s, 3H), 3.64 (s, 3H), 4.00-4.10 (m, 3H), 4.11-4.20 (m, 1H); ¹³C NMR (CDCl₃, 100 MHz) δ 14.0, 25.9, 26.8, 27.0, 35.0, 38.3, 52.3, 52.4, 52.5, 60.8, 60.9, 61.3, 67.0, 83.4, 169.4, 170.0, 170.1, 171.2.

The diastereomeric mixture could be separated via flash chromatography (Hex:EtOAc = 10:1). The *cis*-configuration (higher R_f) was determined to be the major diastereomer by analogy to **1a** wherein the aldehyde proton resonance exists as a doublet. Due to overlapping in the methylene region nOe experiments could not be used to determine the relative configuration. *Cis*-diastereomer: A white solid: IR 2978, 1731, 1447, 1232, 1185, 1044 cm⁻¹; ¹H NMR (CDCl₃, 500 MHz) δ 1.22 (t, J = 7.1 Hz, 3H), 1.27 (t, J = 7.1 Hz, 3H), 1.47 (td, J_{1av} = 13.3 Hz; J_{2av} = 4.3 Hz,

1H), 1.73- 1.84 (m, 4H), 1.98-2.02 (m, 2H), 2.17 (dt, $J = 12.6, 4.0$ Hz, 1H), 3.58 (qd, $J = 13.2, 3.8$ Hz, 1H), 2.53 (d, $J = 14.4$ Hz, 2H), 3.66 (q, $J_{av} = 7.6$ Hz, 1H), 3.77- 3.80 (m, 1H), 4.11-4.20 (m, 3H), 4.23- 4.29 (m, 1H), 9.64 (d, $J = 3.6$ Hz, 1H); ^{13}C NMR (100 MHz) δ 14.0, 20.8, 25.7, 29.1, 35.8, 39.9, 52.9(q), 55.6, 61.0, 61.5, 67.5, 81.3(q), 170.7(q), 172.0(q), 205.4(q); MS (LR-APCI): calculated for $\text{C}_{16}\text{H}_{25}\text{O}_6$ 313.17, measured 313.06.

Trans-diastereomer: IR 2978, 1731, 1242, 1184, 1112, 1052 cm^{-1} ; ^1H NMR (CDCl_3 , 500 MHz) δ 1.22 (t, $J = 7.1$ Hz, 3H), 1.26 (t, $J = 7.1$ Hz, 3H), 1.55 (td, $J = 12.8, 3.9$ Hz, 1H), 1.77-1.81 (m, 1H), 1.90-2.01 (m, 4H), 2.05 (d, $J = 14.4$ Hz, 1H), 2.21 (dm, $J = 13.5$ Hz, 1H), 2.31-2.37 (m, 1H), 2.39 (d, $J = 14.4$ Hz, 1H), 2.48 (bs, 1H), 3.71-3.76 (m, 2H), 4.12-4.17 (m, 3H), 4.20-4.27 (m, 1H), 9.76 (s, 1H); ^{13}C NMR (75 MHz) δ 13.9, 20.0, 25.5, 27.3, 35.3, 37.7, 53.2(q), 56.6, 61.0, 61.4, 66.2, 80.9(q), 170.9(q), 171.7(q), 202.8.

14a and **14b** were separated via flash via flash chromatography (Hex:EtOAc = 2:1 then 4:5).

A colorless oil ($R_f \sim 0.7$ in 4:5 hexanes:EtOAc).

The relative configuration was confirmed via nOe experiments: IR 2980, 1729, 1450, 1262, 1239, 1052, 1023 cm^{-1} ; ^1H NMR (CDCl_3 , 500 MHz) δ

1.09 (qd, $J = 14.2, 3.1$ Hz, 1H), 1.24-1.31 (m, 6H), 1.72-1.78 (m, 1H), 1.80-1.87 (m, 2H), 1.98 (td, $J = 3.4, 14.4$ Hz, 1H), 2.16-2.26 (m, 2H), 3.10 (dt, $J = 12.6, 7.3$ Hz, 1H), 3.92 (q, $J = 8.9$ Hz, 1H), 4.02 (td, $J_{av1} = 6.3$ Hz; $J_{av2} = 2.8$ Hz, 1H), 4.15-4.29 (m, 4H), 4.55 (dd, $J = 10.4, 6.8$ Hz, 1H), 9.75 (d, $J = 1.4$ Hz, 1H); ^{13}C NMR (75 MHz) δ 14.3, 19.8, 25.0, 26.1, 41.6, 51.1, 56.5(q), 61.6, 61.8, 66.0, 75.1, 169.7(q), 170.5(q), 203.9.

A colorless oil ($R_f \sim 0.2$ in 4:5 Hex:EtOAc). The

relative configuration was confirmed via nOe experiments: IR 2981, 1729, 1686, 1249, 1192, 1151, 1052, 1025 cm^{-1} ; ^1H NMR (CDCl_3 , 500

MHz) δ 1.30 (t, $J = 7.1$ Hz, 3H), 1.85-1.91 (m, 1H), 1.93-1.99 (m, 1H), 2.20-2.29 (m, 1H), 2.37-2.43 (m, 1H), 2.47-2.53 (m, 2H), 3.46-3.49 (m, 1H), 4.24-4.31 (m, 3H), 4.35-4.39 (m, 1H), 6.58 (t, $J = 3.1$ Hz, 1H), 9.50 (s, 1H); ^{13}C NMR (75 MHz) δ 14.0, 18.4, 26.2, 27.6, 36.3, 53.8(q), 62.6, 66.9, 142.1, 147.3(q), 168.4 (q), 170.7(q), 192.4; MS (LR-APCI): calculated for $\text{C}_{13}\text{H}_{17}\text{O}_5$ 253.11, measured 253.03.

A colorless oil (SiO_2 , Hex:EtOAc = 1:1). The

relative configuration was confirmed via nOe experiments: IR 1729, 1704, 1451, 1389, 1264, 1231, 1111, 1022 cm^{-1} ; ^1H NMR (DMSO- d_6 , 360K, 300 MHz) δ 1.20 (sextet, $J_{av} = 3.6$ Hz,

6H), 1.56-1.70 (m, 2H), 1.81-2.10 (m, 3H), 2.26-2.36 (m, 2H), 2.85 (pentet, $J = 6.7$ Hz, 1H), 3.38-3.43 (m, 2H), 3.57 (s, 3H), 4.10-4.29 (m, 5H), 9.53 (d, $J = 3.4$ Hz, 1H); ^{13}C NMR (DMSO- d_6 , 360K, 75 MHz) δ 13.2, 19.7, 23.5, 40.0, 43.3, 50.9,

51.4, 54.6, 55.5, 60.7, 61.0, 154.1(br), 168.8, 169.9, 201.9.

The assigned stereochemistry follows from the observation of the coupling constant ($J = 9.8$ Hz) in the signal in the methine protons. In *trans*-2,3-substituted tetrahydropyrans J values in the range 9.5-12 Hz have been observed.² A colorless oil (SiO₂, Hex:EtOAc = 3:1): IR 2938, 2851, 1709, 1360, 1096, 1080, 1036, 933, 758, 700 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.68 (s, 3H), 1.66-1.85 (m, 3H), 1.99-2.03 (m, 1H), 2.88 (td, 10.4, 3.9 Hz, 1H), 3.60 (td, $J_{1av} = 11.2$ Hz; $J_{2av} = 3.3$ Hz, 1H), 4.10 (dm, $J = 13.0$ Hz, 1H), 4.35 (d, $J = 9.8$ Hz, 1H), 7.21-7.30 (m, 5H); ¹³C NMR (CDCl₃, 75 MHz) δ 24.9, 26.9, 31.0, 56.6, 68.5, 81.7, 126.9, 128.1, 128.5, 140.5, 210.4; MS (LR-APCI): calculated for C₁₃H₁₇O₂ 205.12, measured 205.88.

A colorless oil (SiO₂, Hex:EtOAc = 9:1 then 6:1): IR 2951, 1727, 1611, 1516, 1462, 1254, 1194, 1041, 828 cm⁻¹; ¹H NMR (CDCl₃, 500 MHz) δ 0.79 (s, 3H), 1.06 (s, 3H), 1.28-1.33 (m, 1H), 1.44-1.49 (m, 1H), 1.54 (s, 3H), 1.74 (d, $J = 8.4$ Hz, 1H), 2.21-2.26 (m, 1H), 2.39-2.45 (m, 2H), 3.59 (s, 3H), 3.66 (s, 3H), 3.77 (s, 3H), 6.78 (d, $J = 5.4$ Hz, 2H), 7.32 (d, $J = 5.4$ Hz); ¹³C NMR (CDCl₃, 75 MHz) δ 27.7, 27.9, 30.2, 30.5, 32.7, 34.8, 43.0, 48.7, 51.8, 51.9, 55.0, 61.7, 112.3, 128.4, 139.4, 157.1, 171.7; MS (LR-APCI): calculated for C₂₀H₂₉O₅ 340.20, measured 349.31.

A white solid (SiO₂, Hex:EtOAc = 15:1): IR 2948, 1728, 1434, 1288, 1247, 1144, 1056, 697 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 1.54-1.69 (m, 6H), 1.72-1.82 (m, 1H), 1.96-2.03 (m, 1H), 2.15-2.23 (m, 2H), 2.38-2.45 (m, 1H), 3.57 (s, 3H), 3.64 (s, 3H), 6.88 (dd, $J = 5.1, 3.7$ Hz, 1H), 6.97 (dd, $J = 3.6, 1.0$ Hz, 1H), 7.12 (dd, $J = 6.8, 1.0$ Hz, 1H); ¹³C NMR (75 MHz) δ 21.2, 21.4, 26.4, 30.0, 37.2, 42.0(q), 51.9, 62.1(q), 123.1, 125.2, 125.6, 151.9(q), 171.1(q), 171.2(q).

Substrates That Failed to Undergo Hydroalkylation

² (a) Yu, C.-M.; Jung, W.-H.; Choi, H.-S.; Lee, J.; Lee, J.-K. *Tetrahedron Lett.* **1995**, 36, 8255. (b) Crombie, L.; Wyvill, R. D. *J. Chem. Soc., Perkin Trans. 1* **1985**, 1971.

sp-7-256
300nb proton standard

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9.4566

6.7921
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sp-7-261 minor
500

km-1-46-data-proton
400MHz

km-I-89-B1
proton 400Mhz

km-I-89-82
proton 400Mhz

Figure 1 displays 20 small line graphs arranged in a grid, showing the variation of the ratio of the maximum value of the function to the value of the function at the point of maximum for different values of the parameter α . The graphs are labeled with α values from 0.00 to 0.99 in increments of 0.01. Each graph plots the ratio (y-axis) against an unlabeled x-axis. The curves generally show a peak that shifts and changes shape as α increases.

km-I-86 H1
400

kmn-I-data-prot.on
400MHz

sp-7-210
proton 400Mhz

005

standard proton

SP-7-236
400

sp-7-238
500

KRM-I-53-data proton
400Mhz

sp-7-40
500

sp-7-240
minor diastereomer
500 standard proton

sp-7-216
400

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05CS-6

SP-7-237
500

sp-7-263
300wb proton

sp-7-265
300 w5