Asymmetric Conjugate Addition Reactions of Meldrum's Acid Derived Acceptors Employing Chiral Phosphoramidite Ligands

Takumi Watanabe, Thomas F. Knöpfel and Erick M. Carreira*

Laboratorium für Organische Chemie
ETH-Hönggerberg HCI H335
CH-8093 Zürich, Switzerland.
Carreira@org.chem.ethz.ch

Experimental

General Information:

For the reactions, solvents were purified by distillation and dried by passage over activated alumina under an argon atomosphere (H_2O content < 30 ppm, *Karl-Fischer* titration). For flash chromatography and extractions technical grade solvents were used, which were distilled prior to use. All chemicals were purchased from Aldrich or Fluka and used as received.

Chromatographic purification was performed as flash chromatography using Merck silica gel 60 with 0.4 bar pressure.

TLC was performed on Merck silica gel 60 F254 TLC glass plates and visualized with UV light and/or permanganate stain.

^{1}H-NMR spectra were recorded on a VARIAN Mercury 300 MHz spectrometer in chloroform-d. All signals are reported in ppm relative to TMS with the internal solvent signal ($CDCl_3$: 7.26) as standard. The data is reported as (s=singlet, d= doublet, t=triplet, m=multiplet or unsolved signal, coupling constant(s) in Hz, integration).

^{13}C-NMR spectra were recorded with ^{1}H-decoupling on VARIAN Mercury 75 MHz spectrometer in chloroform-d, all signals are reported in ppm relative to TMS with the internal solvent signal ($CDCl_3$: 77.0) as standard.

Infrared spectra were recorded on a Perkin-Elmer spectrum RX-I FT-IR spectrometer as thin films or KBr pellets. The data is being reported as absorption maxima (ν, cm^{-1}) with corresponding characteristic intensity (w=weak, m=medium, s=strong).

Melting points were measured on a Buechi 510 melting point apparatus using open glass capillaries and are uncorrected.

Mass spectrometric measurements were performed by the mass spectrometry service of the LOC at the ETHZ.

Combustion analyses were performed by the Mikroelementarische Laboratorium of the LOC at the ETHZ.

Enantiomeric excesses were determined by chiral HPLC analysis of derivatives of adducts (anilides of corresponding monocarboxylic acid) with Merck-Hitachi D-7000 system. Solvent mixtures, conditions, retention times and Chiracel columns used are given in parentheses.

Optical rotation $[\alpha]^{25}_{D}$ were measured by Jasco DID-1000 or DID-1030 Polarimeter, 10 cm 1 mL cell. Concentration (c, g/100 mL), solvent and ee of the each sample are given in parentheses.

Preparation of chiral ligand

(*R*,*R*)-Bis-(1-cyclohexyl-ethyl)-(3,5-dioxa-4-phospha-cyclohepta[2,1-a;3,4-a']-(*S*)-dinaphthalen-4-yl)-amine (**3**).

A chiral ligand **3** was synthesized according to a reported procedure[1)]. The title compound (128.6 mg, 0.234 mmol) was obtained as a white foam in 68% yield from 98.5 mg (0.344 mmol) of BINOL and 47.2 mg (0.344 mmol) of (*R*,*R*)-Bis-(1-cyclohexyl-ethyl)-amine[2)]; $[\alpha]^{25}_{D}$ +301 ° (c=0.93, $CHCl_3$) ^1H NMR δ 0.60-2.10 (m, 28H), 2.96 (m, 2H), 7.17-7.28 (m, 3H), 7.35-7.50 (m, 5H), 7.84-7.98 (m, 4H); ^{13}C NMR δ 18.9, 26.4, 26.5, 26.6, 26.8, 27.0, 29.67, 29.72, 29.9, 31.6, 32.2, 43.1, 54.7, 54.8, 121.3, 121.6, 122.4, 123.99, 124.05, 124.4, 125.5, 125.7, 127.0, 128.0, 128.1, 129.0, 129.1, 130.0, 130.2, 131.2, 132.6, 149.8, 150.4, 150.6; FTIR (thin film): 2924 (s), 1733 (w), 1621 (w), 1592 (m), 1506 (m), 1463 (s), 1448 (m), 1373 (m), 1329 (s), 1230 (s), 1072 (m), 941 (s), 821 (m); HRMS (FT MALDI) calcd for $C_{17}H_{24}NO_4$ $(MH)^+$ 552.3031 found 552.3023.

Preparation of Meldrum's alkylidenes.

All the substrates except for **1i** have been reported in literature (**1a, c, d, f, k**[3)], **1b, l**[4)], **1e, h**[5)], **1g**[6)], **1j**[7)]). The compound **1i** was prepared according to the method reported by Bigi et al.[3)].

2,2-Dimethyl-5-(4-trifluoromethyl-benzylidene)-[1,3]dioxane-4,6-dione (1i)

White powder: mp 134-135 °C; ^1H NMR δ 1.83 (s, 6H), 7.72 (d, *J*=7.2 Hz, 2H), 8.06 (d, *J*=7.2 Hz, 2H), 8.44 (s, 1H); ^{13}C NMR δ 27.8, 104.9, 117.2, 123.3, 125.4, 132.7, 133.9, 134.7, 155.6, 159.0, 162.3; FTIR (KBr): 1733 (s), 1631 (s), 1386 (m), 1327 (m), 1296 (m), 1202 (m), 1171 (m), 1124 (m), 1066 (m), 1037 (w), 933 (w), 842 (m); MS (ESI neg.) calcd for $C_{14}H_{11}F_3O_4$ (M^-) 300.1 found 300.0; Anal. Calcd for $C_{14}H_{11}F_3O_4$: C, 56.01; H, 3.69. Found: C, 55.72; H, 3.50.

General procedure for the conjugate addition of diethylzinc to Meldrum's alkylidenes

To a solution of **3** (5.5 mg; 9.97 μmol, 6 mol%) and $Cu(O_2CCF_3)_2$ (962.3 μg, 3.32 μmol, 2 mol%) in THF (0.2 mL) was added a 1.2 eq. of 1 M solution of Et_2Zn in hexane (199.4 μL, 0.199 mmol) and a solution of a Meldrum's alkylidene (0.166 mmol) in 0.3 mL of THF (or the least amount of THF to dissolve the substrate) at -78 °C successively. The reaction was stirred for 3h at the temperature, quenched with 0.5 N HCl. The mixture was extracted with CH_2Cl_2 three times. The combined organic layers were washed with brine, dried over Na_2SO_4 and concentrated in vacuo. The resulting residue was purified by flash column chromatography (SiO_2, hexanes:EtOAc) to give the pure product.

For some substrates, 1 mol% of $Cu(O_2CCF_3)_2$ and 3 mol% of ligand were used.

A small amount of adduct was converted to the anilide of the corresponding monocarboxylic acid (stirred at 100 °C for 1 h in DMF:aniline=10:1), of which the ee was determined by HPLC.

***(R)*-(-)-5-(1-Ethyl-2-methyl-propyl)-2,2-dimethyl-[1,3]dioxane-4,6-dione (2a).**

The compound (32.9 mg, 0.144 mmol) was obtained from the **1a** (32.9 mg, 0.166 mmol) in 87% yield. Physicochemical properties were identical to reported ones8): $[\alpha]^{25}_{D}$ -3.98 ° (c=1.065, $CHCl_3$, 91% ee). The enantioselectivity was 92% ee (Daicel Chiracel OD-H column (15 cm) with hexane:2-propanol=92:8, flow 1 mL/min, retention time: 8.5 min: *R*-enantiomer, 9.7 min: *S*-enantiomer).

The absolute configuration was determined by optical rotation of 3-ethyl-4-pentanol9) derived from **2a** ((i) wet DMF, 100 °C, (ii) $LiAlH_4$).

***(R)*- (-)-5-(1-Cyclohexyl-propyl)-2,2-dimethyl-[1,3]dioxane-4,6-dione (2b).**

The compound (37.5 mg, 0.140 mmol) was obtained from the **1b** (39.6 mg, 0.166 mmol) in 84% yield as a white solid: mp 98-99 °C; $[\alpha]^{25}_{D}$ -11.9 ° (c=0.125, $CHCl_3$); ^1H NMR δ 0.92 (t, *J*=7.5 Hz, 3H), 0.90-1.30 (m, 6H), 1.50-1.80 (m, 6H), 1.93 (m, 1H), 2.25 (ddt, *J*=4.5, 2.4, 9.0 Hz, 1H), 3.53 (d, *J*=2.4 Hz, 1H); ^{13}C NMR δ 13.2, 23.3, 26.38, 26.45, 26.6, 27.6, 28.2, 31.6, 31.8, 39.8, 45.8, 46.7, 104.5, 165.9; FTIR (KBr): 2930 (s), 1783 (s), 1742 (s), 1386 (m), 1315 (s), 1208 (m), 1057 (w), 993 (m), 907 (w), 874 (m); MS (ESI neg.) calcd for $C_{15}H_{23}O_4$ $(M-H)^-$ 267.2 found 267.1; Anal. Calcd for $C_{15}H_{24}O_4$: C, 67.14; H, 9.01. Found: C, 67.06; H, 9.05.

The enantioselectivity was 94% ee (Daicel Chiracel OD-H (15 cm) column with hexane:2-propanol=92:8, flow 1 mL/min, retention time: 8.5 min: *R*-enantiomer, 10.3 min: *S*-enantiomer).

The absolute configuration was determined by the sign of optical rotation of 3-cyclohexylpentanic acid10) derived from **2b** (wet DMF, 100 °C).

***(R)*-(+)-2,2-Dimethyl-5-(1-phenyl-propyl)-[1,3]dioxane-4,6-dione (2c).**

The compound (41.1 mg, 0.157 mmol) was obtained from the **1c** (38.6 mg, 0.166 mmol) in 94% yield. Physicochemical properties were as reported8): $[\alpha]^{25}_{D}$ +10.0 (c=4.395, $CHCl_3$, 31% ee).

and The enantioselectivity was 40% ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 13.1 min: *S*-enantiomer, 16.4 min: *R*-enantiomer)

Absolute configuration was confirmed as follows; the adduct **2c** was converted to 1,3-diphenyl-1-pentanone in 3 steps ((i) wet DMF for 1 hr at 100 °C (ii) $SOCl_2$, then N,O-dimethylhydroxylamine hydrochloride and pyridine (iii) PhLi /THF). A condition of chiral columun HPLC to determine the ee of the resulting ketone has been reported by Fu et al.11)

(*R*)-(+)-5-[1-(4-Methoxy-phenyl)-propyl]-2,2-dimethyl-[1,3]dioxane-4,6-dione (2d).

The compound (33.4 mg, 0.114 mmol) was obtained from 44.4 mg (0.161 mmol) of the substrate **1d** with 5.30 mg (9.61 μmol) and 927 μg (3.20 μmol) of $Cu(O_2CCF_3)_2$ in 71 % yield as a colorless oil: $[\alpha]^{25}_{D}$ +4.24 (c=1.37, EtOH, 75% ee). ^{1}H NMR δ 0.93 (t, *J*=7.4 Hz, 3H), 1.17 (s, 3H), 1.63 (s, 3H), 2.06 (m, 1H), 2.25 (m, 1H), 3.61 (m, 1H), 3.67 (d, *J*=3.3 Hz, 1H), 3.77 (s, 3H), 6.83 (d, *J*=8.7 Hz, 2H), 7.20 (d, *J*=8.7 Hz, 2H); ^{13}C NMR δ 12.7, 26.0, 28.2, 28.5, 47.5, 51.1, 55.2, 105.4, 113.9, 130.0, 131.3, 158.8, 164.7, 165.9; FTIR (thin film): 2968 (s), 1747 (s), 1612 (m), 1514 (s), 1463 (m), 1393 (m), 1383 (m), 1295 (s), 1251 (s), 1208 (m), 1181 (m), 1034 (m), 998 (m), 890 (w); MS (ESI neg.) calcd for $C_{16}H_{19}O_5$ $(M-H)^-$ 291.1 found 291.0; Anal. Calcd for $C_{16}H_{20}O_5$: C, 65.74; H, 6.90. Found: C, 65.97; H, 6.97.

The enantioselectivity was 87 % ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 18.8 min: *S*-enantiomer, 23.8 min: *R*-enantiomer).

Absolute configuration was confirmed as follows; the adduct was converted to 3-(4-Methoxy-phenyl)-1-phenyl-pentan-1-one in 3 steps ((i) wet DMF for 1 hr at 100 °C (ii) $SOCl_2$, then N,O-dimethylhydroxylamine hydrochloride and pyridine (iii) PhLi /THF). A condition of chiral columun HPLC to determine the ee of the resulting ketone is the one reported by Fu et al.[11)]

(-)-5-[1-(4-Dimethylamino-phenyl)-propyl]-2,2-dimethyl-[1,3]dioxane-4,6-dione (2e).

The substrate **1e** (79.2 mg, 0.332 mmol), chiral ligand (5.50 mg, 9.97 μmol, 3 mol%) and $Cu(O_2CCF_3)_2$ (962 μg, 3.32 μmol, 1 mol%) were employed and the reaction was quenched by saturated NH_4Cl aqueous solution. The aqueous layer was extracted with CH_2Cl_2 three times. The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by flash column chromatography (SiO_2, hexanes:EtOAc=5:1) to give the pure product (91.5 mg, 0.300 mmol) in 90% yield as a white solid: mp 96-97 °C; $[\alpha]^{25}_{D}$ -3.96 ° (c=1.13, $CHCl_3$, 88% ee); ^{1}H NMR δ 0.93 (t, *J*=7.4 Hz, 3H), 1.12 (s, 3H), 1.61 (s, 3H), 2.05 (m, 1H), 2.21 (m, 1H), 2.90 (s, 6H), 3.54 (m, 1H), 3.66 (d, *J*=3.0 Hz, 1H), 6.65 (d, *J*=9.0 Hz, 2H), 7.13 (d, *J*=9.0 Hz, 2H); ^{13}C NMR δ 12.8, 26.1, 28.2, 28.6, 40.6, 47.7, 51.2, 105.4, 112.5, 126.9, 129.5, 149.9, 164.8, 166.2; FTIR (KBr): 2968 (s), 1760 (s), 1738 (s), 1610 (m), 1520 (s), 1457 (m), 1380 (m), 1341 (m), 1293 (s), 1205 (m), 1129 (w), 1003 (m), 820 (m); HRMS (FT MALDI) calcd for $C_{17}H_{24}NO_4$ $(MH)^+$ 306.1705 found 306.1695.

The enantioselectivity was 88% ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 16.1 min: minor, 22.1 min: major)

(+)-5-[1-(4-Chloro-phenyl)-propyl]-2,2-dimethyl-[1,3]dioxane-4,6-dione (2f).

The compound (34.0 mg, 0.115 mmol) was obtained from 45.2 mg (0.172 mmol) of the substrate **1f**

with 5.70 mg (10.3 μmol) of ligand **3** and 997 μg (3.44 μmol) of $Cu(O_2CCF_3)_2$ in 67 % yield as a colorless oil: $[\alpha]^{25}_D$ +9.63 ° (c=1.265, $CHCl_3$, 33% ee); ^{1}H NMR δ 0.93 (t, *J*=7.2 Hz, 3H), 1.37 (s, 3H), 1.67 (s, 3H), 2.05 (m, 1H), 2.30 (m, 1H), 3.72 (d, *J*=3.0 Hz, 1H), 3.75 (m, 1H), 7.48 (d, *J*=8.4 Hz, 2H), 7.66 (d, *J*=8.4 Hz, 2H); ^{13}C NMR δ 12.7, 25.6, 28.18, 28.21, 46.9, 51.0, 105.2, 128.6, 130.5, 133.3, 137.8, 164.4, 165.3; FTIR (thin film): 2970 (s), 1748 (s), 1596 (w), 1494 (s), 1394 (m), 1384 (m), 1300 (s), 1209 (m), 1092 (m), 999 (m), 900 (w), 861 (w), 833 (m); MS (ESI neg.) calcd for $C_{15}H_{16}ClO_4$ $(M-H)^-$ 295.1 found 295.1; Anal. Calcd for $C_{15}H_{17}ClO_4$: C, 60.71; H, 5.77. Found: C, 60.64; H, 5.84.
The enantioselectivity was 44 % ee (Daicel Chiracel OD-H column (25 cm) with hexane:2-propanol=92:8, flow 0.8 mL/min, retention time: 23.8 min; major, 29.6 min; minor)

(+)-5-[1-(4-Bromo-phenyl)-propyl]-2,2-dimethyl-[1,3]dioxane-4,6-dione (2g).
The compound (34.5 mg, 0.101 mmol) was obtained from 51.7 mg (0.166 mmol) of the substrate **1g** in 61 % yield as a colorless oil: $[\alpha]^{25}_D$ +6.00 ° (c=0.895, $CHCl_3$, 34% ee); ^{1}H NMR δ 0.92 (t, *J*=7.4 Hz, 3H), 1.34 (s, 3H), 1.67 (s, 3H), 2.03 (m, 1H), 2.26 (m, 1H), 3.64 (m, 1H), 3.68 (d, *J*=3.0 Hz, 1H), 7.21 (d, *J*=6.9 Hz, 2H), 7.42 (d, *J*=6.9 Hz, 2H); ^{13}C NMR δ 12.7, 25.5, 28.2, 47.0, 50.9, 105.2, 121.5, 130.8, 131.6, 138.3, 164.4, 165.2; FTIR (thin film): 1745 (s), 1489 (w), 1383 (w), 1294 (s), 1206 (m), 1075 (w), 1010 (m), 830 (w); MS (ESI neg.) calcd for $C_{15}H_{16}BrO_4$ $(M-H)^-$ 339.0 found 338.9; Anal. Calcd for $C_{15}H_{17}BrO_4$: C, 52.80; H, 5.02. Found: C, 52.86; H, 5.14.
The enantioselectivity was 45 % ee (Daicel Chiracel OD-H column (15 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 9.32 min; major, 11.0 min; minor)

(+)-2,2-Dimethyl-5-(1-*p*-tolyl-propyl)-[1,3]dioxane-4,6-dione (2h).
The compound (36.0 mg, 0.130 mmol) was obtained from 40.9 mg (0.166 mmol) of the substrate **1h** in 78 % yield as a white solid: mp 61-62 °C $[\alpha]^{25}_D$ +2.64 ° (c=1.96, $CHCl_3$, 34% ee); ^{1}H NMR δ 0.93 (t, *J*=7.2 Hz, 3H), 1.15 (s, 3H), 1.62 (s, 3H), 2.06 (m, 1H), 2.26 (m, 1H), 2.30 (s, 3H), 3.61 (m, 1H), 3.66 (d, *J*=2.4 Hz, 1H), 7.10 (d, *J*=8.2 Hz, 2H), 7.18 (d, *J*=8.2 Hz, 2H); ^{13}C NMR δ 12.7, 21.1, 25.8, 28.1, 28.5, 47.8, 51.1, 105.4, 128.8, 129.2, 136.2, 137.2, 164.6, 165.8; FTIR (KBr): 2964 (m), 1780 (s), 1743 (s), 1514 (w), 1455 (w), 1384 (m), 1316 (m), 1298 (s), 1208 (m), 1174 (m), 1067 (m), 1007 (m), 887 (w), 861 (w); MS (ESI neg.) calcd for $C_{16}H_{19}O_4$ $(M-H)^-$ 275.1 found 275.1; Anal. Calcd for $C_{16}H_{20}O_4$: C, 69.55; H, 7.29. Found: C, 69.44; H, 7.25.
The enantioselectivity was 44 % ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 12.6 min; minor, 16.0 min; major)

(+)-2,2-Dimethyl-5-[1-(4-trifluoromethyl-phenyl)-propyl]-[1,3]dioxane-4,6-dione (2i).
The compound (77.6 mg, 0.235 mmol) was obtained from 98.2 mg (0.332 mmol) of the substrate **1i** with the ligand **3** (5.50 mg; 9.97 μmol, 3 mol%) and $Cu(O_2CCF_3)_2$ (962 μg, 3.32 μmol, 1 mol%) in

72 % yield as a colorless oil: [α]$^{25}_{D}$ +3.02 (c=1.41, EtOH, 62% ee). ^{1}H NMR δ 0.93 (t, *J*=7.2 Hz, 3H), 1.37 (s, 3H), 1.67 (s, 3H), 2.06 (m, 1H), 2.30 (m, 1H), 3.72 (d, *J*=3.0 Hz, 1H), 3.74 (m, 1H), 7.48 (d, *J*=8.4 Hz, 2H), 7.56 (d, *J*=8.4 Hz, 2H); ^{13}C NMR δ 12.7, 25.3, 28.0, 28.1, 47.0, 50.9, 105.2, 125.4, 125.5, 129.6, 129.7, 143.5, 164.3, 164.9; FTIR (thin film): 1747 (s), 1327 (s), 1294 (m), 1166 (w), 1125 (m), 1069 (w); MS (ESI neg.) calcd for $C_{16}H_{16}F_3O_4$ (M-H)$^-$ 329.1 found 329.0; Anal. Calcd for $C_{16}H_{17}F_3O_{45}$: C, 58.18; H, 5.19. Found: C, 58.28; H, 5.20.

The enantioselectivity was 62 % ee (Daicel Chiracel OD-H column (15 cm) with hexane:2-propanol=92:8, flow 1.0 mL/min, retention time: 9.31 min: major, 11.0 min: minor)

(+)-2,2-Dimethyl-5-(1-naphthalen-2-yl-propyl)-[1,3]dioxane-4,6-dione (2j).

The compound (43.3 mg, 0.139 mmol) was obtained from 46.9 mg (0.166 mmol) of the substrate **1j** in 83 % yield as a colorless oil: [α]$^{25}_{D}$ +10.2 ° (c=1.615, $CHCl_3$, 37% ee); ^{1}H NMR δ 0.96 (t, *J*=7.4 Hz, 3H), 1.10 (s, 3H), 1.62 (s, 3H), 2.15 (m, 1H), 2.42 (m, 1H), 3.78 (d, *J*=3.3 Hz, 1H), 3.84 (m, 1H), 7.42-7.48 (m, 3H), 7.76-7.83 (m, 4H); ^{13}C NMR δ 12.8, 25.8, 28.1, 28.3, 48.0, 51.2, 105.3, 125.9, 126.0, 126.6, 127.4, 127.9, 128.2, 132.6, 133.2, 136.8, 164.7, 165.6; FTIR (thin film): 1747 (s), 1394 (w), 1383 (w), 1295 (s), 1209 (m), 997 (w); MS (ESI neg.) calcd for $C_{19}H_{19}O_4$ (M-H)$^-$ 311.1 found 311.0; Anal. Calcd for $C_{19}H_{20}O_4$: C, 73.06; H, 6.45. Found: C, 73.02; H, 6.71.

The enantioselectivity was 67 % ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 17.2 min; minor, 22.3 min; major)

(+)-5-(1-Furan-2-yl-propyl)-2,2-dimethyl-[1,3]dioxane-4,6-dione (2k).

The compound (22.4 mg, 88.7 μmol) was obtained from 30.9 mg (0.139 mmol) of the substrate **1k** with 4.60 mg (8.34 μmol) of ligand **3** and 804 μg (2.78 μmol) of $Cu(O_2CCF_3)_2$ in 64 % yield as a colorless oil: [α]$^{25}_{D}$ +8.71 ° (c=0.630, $CHCl_3$, 76% ee); ^{1}H NMR δ 1.01 (t, *J*=7.5 Hz, 3H), 1.54 (s, 3H), 1.73 (s, 3H), 1.93 (m, 1H), 2.21 (m, 1H), 3.75 (d, *J*=3.0 Hz, 1H), 3.79 (m, 1H), 6.20 (d, *J*=3.0 Hz, 1H), 6.30 (dd, *J*=1.8, 3.0 Hz, 1H), 7.31 (d, *J*=1.8 Hz, 1H); ^{13}C NMR δ 12.6, 24.4, 27.9, 28.2, 40.8, 48.7, 105.1, 107.3, 110.4, 141.3, 153.6, 164.2, 164.9; FTIR (thin film): 1783 (m), 1748 (s), 1384 (w), 1295 (s), 1206 (m), 1009 (w); MS (ESI neg.) calcd for $C_{13}H_{15}O_5$ (M-H)$^-$ 251.1 found 251.1; Anal. Calcd for $C_{13}H_{16}O_5$: C, 61.90; H, 6.39. Found: C, 61.89; H, 6.59.

The enantioselectivity was 80 % ee (Daicel Chiracel AD-H column (25 cm) with hexane:2-propanol=90:10, flow 0.8 mL/min, retention time: 13.7 min; minor, 16.1 min; major)

(+)-2,2-Dimethyl-5-(1-thiophen-2-yl-propyl)-[1,3]dioxane-4,6-dione (2l).

The literature reported compound **2l**12) (32.9 mg, 0.144 mmol) was obtained in 87% yield from 39.6 mg (0.166 mmol) of the substrate **1l** in 89 % yield as a white solid: [α]$^{25}_{D}$ +4.02 ° (c=0.905, $CHCl_3$); ^{1}H NMR δ 0.98 (t, *J*=7.4 Hz, 3H), 1.36 (s, 3H), 1.69 (s, 3H), 2.06 (m, 1H), 2.28 (m, 1H), 3.72 (d, *J*=3.0

Hz, 1H), 3.98 (m, 1H), 6.93 (dd, *J*=3.6, 5.1 Hz, 1H), 6. (ddd, *J*=0.6, 1.2, 3.6 Hz, 1H), 7.18 (dd, *J*=1.2, 5.1 Hz, 1H); ^{13}C NMR δ 12.8, 27.8, 28.0, 28.3, 42.8, 51.2, 105.3, 124.7, 126.6, 126.8, 142.2, 164.2, 165.2; FTIR (KBr): 1779 (s), 1737 (s), 1461 (w), 1386 (w), 1308 (s), 1202 (m), 1053 (m), 1002 (m), 882 (w), 865 (w); MS (ESI neg.) calcd for $C_{13}H_{15}O_4S$ $(M\text{-}H)^-$ 267.1 found 267.0

The enantioselectivity was 82% ee (Daicel Chiracel OD-H column (15 cm) with hexane:2-propanol=92:8, flow 1 mL/min, retention time: 12.5 min: minor, 15.2 min: major).

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