Supporting Information

Cu(I)-Catalyzed Highly *Exo*-selective and Enantioselective [3+2] Cycloaddition of Azomethine Ylides with Acrylates

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General Methods: Solvents were dried with standard procedures and degassed with N₂. Column chromatography was performed using 200~400 mesh silica gel supplied by Natland International Corporation. Thin layer chromatography (TLC) was performed on EM reagents 0.25 mm silica 60-F plates. ¹H, ¹³C NMR spectrum were recorded on Bruker AM-300, and AMX-360 spectrometers. Chemical shifts were reported in ppm down field from tetramethylsilane with the solvent resonance as the internal standard. Data for ¹H NMR are reported as chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constant (Hz) and integration. Data for ¹³C NMR are reported as chemical shift. Optical rotation was obtained on a Perkin-Elmer 241 polarimeter. MS spectra were recorded on a KRATOS mass spectrometer MS 9/50. HPLC analysis was performed on a Waters 600 Series HPLC, UV detection monitored at 205 nm, using a Chiralcel AS column (25 cm), Chiralpak AS-H column (25 cm) and Chiralcel OJ-H column (25 cm). The relative stereochemistry of the *exo*-adduct and *endo*-adduct was confirmed by NOESY spectrum or by comparison of the proton NMR values with the literature, respectively. The absolute stereochemistry of the *exo*-adduct was confirmed by X-ray study of *exo*-4.

General Procedure for the Synthesis of *N*-Alkylideneglycine Esters **1.** All the *N*-alkylideneglycine esters **1** mentioned in the paper were synthesized according to the known procedure.^[1] A suspension of glycine methyl ester hydrochloride (1.1 eq), excess MgSO₄ and Et₃N (1.1 eq) in CH₂Cl₂ was stirred at rt for 1h. The aldehyde (1.0 eq) was added and the reaction was stirred at rt overnight. The MgSO₄ was removed by filtration and the filtrate was washed once with H₂O. The aqueous phase was extracted once with CH₂Cl₂ and the combined organic layers were washed with brine. The organic phase was dried over Na₂SO₄, filtered and concentrated. Most products were sufficiently pure but if necessary could be purified by either recrystallization or bulb-to-bulb distillation.

The copper (I) catalyzed cycloaddition of imine **1 and dipolarophiles **2**.**

General procedure: The catalyst was prepared by stirring Cu(CH₃CN)₄ClO₄ (8.2 mg, 0.025 mmol, 5 mol%) and ligand **L4** (15.1 mg, 0.0275 mmol, 5.5 mol%) in THF (2 mL) for 1 hour at room temperature. Then the mixture was cooled to -25 °C, imine substrate **1** (0.50 mmol), dipolarophile **2** (0.75 mmol, 1.5 equiv.) and base (0.05 mmol, 10 mol%) were added subsequently and the resulting mixture was stirred at -25 °C for 20 hours. When the reaction was complete as monitored by TLC, the mixture was passed through a short column of silica gel and the diastereometric ratio (*exo/endo*) was determined by the NMR spectroscopic analysis of the crude product. Then the pure adducts was purified by column chromatography on silica gel (Hexanes/ethyl acetate/1% triethylamine).

(1) **5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid**

4-tert-butyl ester 2-methyl ester (*exo*-3a): Prepared according to the general procedure with **1a** (105.5 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 μ L, 0.75 mmol) to afford the title compound in 85% yield (144.1 mg) and the undesired *endo*-adduct in 4% yield (7.0 mg) after silica chromatography (EtOAc/Hex containing 1% Et₃N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 96/4; 91% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{minor}} = 17.0$ min, $t_{\text{major}} = 22.4$ min. $[\alpha]_{\text{D}}^{25} = -37.4^{\circ}$ ($c = 1.37$, CH₂Cl₂). ¹H NMR (360 MHz, CDCl₃) δ 7.39 (d, $J = 8.5$ Hz, 2 H), 7.28 (d, $J = 8.5$ Hz, 2 H), 4.31 (d, $J = 8.6$ Hz, 1 H), 4.00 (dd, $J = 8.8$ and 5.3 Hz, 1 H), 3.76 (s, 3 H), 2.74 (q, $J = 8.8$ Hz, 1 H), 2.45 (dt, $J = 13.0$ and 8.8 Hz, 1 H), 2.35-2.25 (m, 2 H), 1.35 (s, 9 H); ¹³C NMR (90 MHz, CDCl₃) δ 175.0, 172.6, 140.7, 133.7, 129.0, 128.8, 81.5, 66.4, 59.5, 52.8, 52.6, 34.5, 28.4; MS (m/z) 340.1 ($M+1$, 100); HRMS calcd for C₁₇H₂₃NO₄Cl [$M+H$] 340.1310. Found 340.1297.

5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid 4-

tert-butyl ester 2-methyl ester (*endo*-3a):^[2] 5 % ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 10: 90, 1.0 ml/min, $t_{\text{major}} = 6.8$ min, $t_{\text{minor}} = 18.0$ min. ¹H NMR (360 MHz, CDCl₃) δ 7.35-7.25 (m, 4 H), 4.44 (d, $J = 7.8$ Hz, 1 H), 3.94 (t, $J = 8.2$ Hz, 1 H), 3.80 (s, 3 H), 3.24 (q, $J = 7.8$ Hz, 1 H), 2.55 (br, 1 H), 2.43 (dt, $J = 13.3$

and 8.2 Hz, 1 H), 2.35-2.25 (m, 1 H), 1.06 (s, 9 H); ^{13}C NMR (90 MHz, CDCl_3) δ 174.0, 171.9, 138.5, 133.5, 129.1, 128.6, 81.2, 65.2, 60.2, 52.6, 50.5, 34.2, 27.9; MS (m/z) 340.2 (M+1, 65), 284.1 (100).

(2): 5-(2-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid 4-

tert-butyl ester 2-methyl ester (*exo*-3b): Prepared according to the general procedure with **1b** (105.5 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 μL , 0.75 mmol) to afford the title compound in 71% yield (120.6 mg) and the undesired *endo*-adduct in 20 % yield (35.0 mg) after silica chromatography (EtOAc/Hex containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 76/24; 98% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{major}} = 11.3$ min, $t_{\text{minor}} = 14.1$ min. $[\alpha]_{\text{D}}^{25} = +4.5^\circ$ ($c = 0.80$, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3) δ 7.78 (dd, $J = 7.8$ and 1.7 Hz, 1 H), 7.35-7.25 (m, 2 H), 7.22-7.15 (m, 1 H), 4.90 (d, $J = 6.3$ Hz, 1 H), 4.11 (t, $J = 7.8$ Hz, 1 H), 3.78 (s, 3 H), 2.90 (dt, $J = 8.3$ and 6.1 Hz, 1 H), 2.55-2.40 (m, 2 H), 2.25 (dt, $J = 12.9$ and 8.0 Hz, 1 H), 1.40 (s, 9 H); ^{13}C NMR (75 MHz, CDCl_3) δ 174.5, 172.4, 139.9, 133.1, 129.2, 128.5, 128.4, 127.0, 80.9, 61.2, 59.3, 52.1, 51.5, 33.0, 27.8; MS (m/z) 340.1 (M+1, 100); HRMS calcd for $\text{C}_{17}\text{H}_{23}\text{NO}_4\text{Cl}$ [M+H] 340.1310. Found 340.1319.

5-(2-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid 4-tert-

butyl ester 2-methyl ester (*endo*-3b): 42 % ee. Product ratio was determined by HPLC,

Chiralpak AS column, IPA/Hex = 10: 90, 1.0 ml/min, $t_{\text{major}} = 5.8$ min, $t_{\text{minor}} = 16.9$ min.

^1H NMR (300 MHz, CDCl_3) δ 7.48 (dd, $J = 7.3$ and 1.9 Hz, 1 H), 7.29 (dd, $J = 7.5$ and 1.8 Hz, 1 H), 7.20-7.10 (m, 2 H), 4.64 (d, $J = 7.7$ Hz, 1 H), 3.86 (t, $J = 8.4$ Hz, 1 H), 3.75 (s, 3 H), 3.48-3.40 (m, 1 H), 2.45-2.25 (m, 3 H), 0.93 (s, 9 H); ^{13}C NMR (75 MHz, CDCl_3) δ 173.4, 172.0, 136.4, 133.7, 129.1, 128.5, 127.9, 126.7, 80.5, 62.6, 59.3, 52.2, 47.1, 33.6, 27.4; MS (m/z) 340.2 ($M+1$, 100); HRMS calcd for $\text{C}_{17}\text{H}_{23}\text{NO}_4\text{Cl}$ [$M+H$] 340.1310. Found 340.1310.

(3): 5-(3-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid 4-

tert-butyl ester 2-methyl ester (*exo*-3c): Prepared according to the general procedure

with **1c** (105.5 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 μL , 0.75 mmol) to afford the title compound in 80% yield (136.1 mg) after silica chromatography (EtOAc/Hex

containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the

ratio of *exo/endo* was 96/4; 90% ee. Product ratio was determined by HPLC, Chiralpak

AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{major}} = 12.6$ min, $t_{\text{minor}} = 17.9$ min. $[\alpha]_{\text{D}}^{25} = -$

30.6° ($c = 1.14$, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3) δ 7.49 (s, 1 H), 7.35-7.25 (m, 1

H), 7.24-7.15 (m, 2 H), 4.31 (d, $J = 8.5$ Hz, 1 H), 4.01 (dd, $J = 8.8$ and 5.5 Hz, 1 H), 3.76

(s, 3 H), 2.75 (q, $J = 8.5$ Hz, 1 H), 2.51-2.38 (m, 2 H), 2.37-2.26 (m, 1 H), 1.36 (s, 9 H); ^{13}C NMR (75 MHz, CDCl_3) δ 174.4, 172.1, 143.9, 134.1, 129.6, 127.6, 127.1, 125.1, 81.0, 65.9, 59.0, 52.3, 52.2, 33.8, 27.9; MS (m/z) 340.1 ($M+1$, 100); HRMS calcd for $\text{C}_{17}\text{H}_{23}\text{NO}_4\text{Cl}$ [$M+H$] 340.1310. Found 340.1316.

(4): **5-(4-Fluoro-phenyl)-pyrrolidine-2,4-dicarboxylic acid**

4-tert-butyl ester 2-methyl ester (*exo*-3d): Prepared according to the general procedure with **1d** (97 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 μL , 0.75 mmol) to afford the title compound in 70% yield (111.8 mg) after silica chromatography (EtOAc/Hex containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 94/6; 91% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{minor}} = 14.9$ min, $t_{\text{major}} = 18.1$ min. $[\alpha]_D^{25} = -28.8^\circ$ ($c = 0.84$, CH_2Cl_2). ^1H NMR (360 MHz, CDCl_3) δ 7.42-7.35 (m, 2 H), 7.00-6.90 (m, 2 H), 4.27 (d, $J = 8.7$ Hz, 1 H), 3.97 (dd, $J = 8.9$ and 5.2 Hz, 1 H), 3.72 (s, 3 H), 2.71 (q, $J = 8.7$ Hz, 1 H), 2.48-2.37 (m, 2 H), 2.35-2.25 (m, 1 H), 1.31 (s, 9 H); ^{13}C NMR (90 MHz, CDCl_3) δ 174.6, 172.2, 162.2 (d, $J = 245.5$ Hz), 137.3, 128.5 (d, $J = 8.2$ Hz), 115.1 (d, $J = 21.4$ Hz), 80.8, 66.1, 58.9, 52.4, 52.1, 34.0, 27.8; MS (m/z) 324.2 ($M+1$, 100); HRMS calcd for $\text{C}_{17}\text{H}_{23}\text{NO}_4\text{F}$ [$M+H$] 324.1606. Found 324.1602.

(5): **5-(4-Cyano-phenyl)-pyrrolidine-2,4-dicarboxylic acid**

4-tert-butyl ester 2-methyl ester (*exo*-3e): Prepared according to the general procedure with **1e** (101.0 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 uL, 0.75 mmol) to afford the title compound in 84% yield (138.2 mg) after silica chromatography (EtOAc/Hex containing 1% Et₃N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 95/5; 91% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, *t*_{minor} = 76.6 min, *t*_{major} = 103.2 min. $[\alpha]_D^{rt} = -41.8^\circ$ (*c* = 0.95, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃) δ 7.65-7.60 (m, 4 H), 4.44 (d, *J* = 8.3 Hz, 1 H), 4.05 (dd, *J* = 8.7 and 5.4 Hz, 1 H), 3.77 (s, 3 H), 2.77 (q, *J* = 8.4 Hz, 1 H), 2.52-2.27 (m, 3 H), 1.36 (s, 9 H); ¹³C NMR (75 MHz, CDCl₃) δ 174.5, 171.9, 147.8, 132.2, 127.8, 118.8, 111.3, 81.4, 65.7, 59.0, 52.5, 52.3, 37.8, 27.9; MS (*m/z*) 331.1 (*M*+1, 100); HRMS calcd for C₁₈H₂₃N₂O₄ [*M*+H] 331.1658. Found 331.1639.

(6): **5-phenyl-pyrrolidine-2,4-dicarboxylic acid 4-tert-butyl**

ester 2-methyl ester (*exo*-3f): Prepared according to the general procedure with **1f** (88.0 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 uL, 0.75 mmol) to afford the title compound in 65% yield (98.9 mg) after silica chromatography (EtOAc/Hex containing 1% Et₃N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 95/5; 84% ee. Product ratio was determined by HPLC, Chiralpak OJ-H column, IPA/Hex = 10: 90, 1.0 ml/min, *t*_{major} = 6.4 min, *t*_{minor} = 13.6 min. $[\alpha]_D^{rt} = -19.9^\circ$ (*c* = 0.66, CH₂Cl₂).

^1H NMR (300 MHz, CDCl_3) δ 7.47 (d, $J = 7.7$ Hz, 2 H), 7.40-7.25 (m, 3 H), 4.35 (d, $J = 8.6$ Hz, 1 H), 4.04 (dd, $J = 8.7$ and 5.4 Hz, 1 H), 3.79 (s, 3 H), 2.82 (q, $J = 8.6$ Hz, 1 H), 2.57-2.45 (m, 2 H), 2.40-2.30 (m, 1 H), 1.37 (s, 9 H); ^{13}C NMR (75 MHz, CDCl_3) δ 174.6, 172.3, 141.3, 128.3, 127.5, 126.9, 80.7, 66.9, 59.1, 52.3, 52.1, 34.2, 27.8; MS (m/z) 306.2 ($M+1$, 100); HRMS calcd for $\text{C}_{17}\text{H}_{24}\text{NO}_4$ [$M+H$] 306.1700. Found 306.1702.

(7): **5-(4-Methyl-phenyl)-pyrrolidine-2,4-dicarboxylic acid**

4-tert-butyl ester 2-methyl ester (*exo*-3g): Prepared according to the general procedure with **1g** (95.0 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 μL , 0.75 mmol) to afford the title compound in 61% yield (98.2 mg) after silica chromatography (EtOAc/Hex containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 97/3; 89% ee. Product ratio was determined by HPLC, Chiralpak OJ-H column, $\text{IPA/Hex} = 10:90$, 1.0 ml/min, $t_{\text{major}} = 6.6$ min, $t_{\text{minor}} = 13.8$ min. $[\alpha]_{\text{D}}^{25} = -37.6^\circ$ ($c = 0.85$, CH_2Cl_2). ^1H NMR (360 MHz, CDCl_3) δ 7.35 (d, $J = 8.0$ Hz, 2 H), 7.16 (d, $J = 8.0$ Hz, 2 H), 4.32 (d, $J = 8.6$ Hz, 1 H), 4.04 (dd, $J = 8.7$ and 5.4 Hz, 1 H), 3.79 (s, 3 H), 2.80 (q, $J = 8.6$ Hz, 1 H), 2.57-2.42 (m, 2 H), 2.40-2.30 (m, 4 H), 1.38 (s, 9 H); ^{13}C NMR (90 MHz, CDCl_3) δ 175.1, 172.9, 138.8, 137.6, 129.5, 127.3, 81.1, 67.2, 59.7, 52.8, 52.6, 34.9, 28.4, 21.5; MS (m/z) 320.2 ($M+1$, 100); HRMS calcd for $\text{C}_{18}\text{H}_{26}\text{NO}_4$ [$M+H$] 320.1856. Found 320.1840.

(8): **5-(4-Methoxyphenyl)-pyrrolidine-2,4-dicarboxylic**

acid 4-tert-butyl ester 2-methyl ester (*exo*-3h): Prepared according to the general procedure with **1h** (103.1 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 uL, 0.75 mmol) to afford the title compound in 82% yield (136.0 mg) after silica chromatography (EtOAc/Hex containing 1% Et₃N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 97/3; 91% ee. Product ratio was determined by HPLC, Chiralpak OJ-H column, IPA/Hex = 10: 90, 1.0 ml/min, *t*_{major} = 10.1 min, *t*_{minor} = 24.1 min. $[\alpha]_D^{rt} = -41.0^\circ$ (c = 0.90, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃) δ 7.32 (d, *J* = 8.7 Hz, 2 H), 6.82 (d, *J* = 8.7 Hz, 2 H), 4.22 (d, *J* = 8.7 Hz, 1 H), 3.95 (dd, *J* = 8.8 and 5.2 Hz, 1 H), 3.74 (s, 3 H), 3.72 (s, 3 H), 2.72 (q, *J* = 8.8 Hz, 1 H), 2.50-2.35 (m, 2 H), 2.34-2.23 (m, 1 H), 1.31 (s, 9 H); ¹³C NMR (75 MHz, CDCl₃) δ 174.7, 172.3, 158.9, 133.2, 128.0, 113.6, 80.6, 66.4, 58.9, 55.0, 52.2, 52.1, 34.3, 27.8; MS (*m/z*) 336.2 (*M*+1, 100); HRMS calcd for C₁₈H₂₆NO₅ [*M*+H] 336.1806. Found 336.1798.

(9): **5-Naphthalen-2-yl-pyrrolidine-2,4-dicarboxylic acid 4-**

tert-butyl ester 2-methyl ester (*exo*-3i): Prepared according to the general procedure with **1i** (114.2 mg, 0.50 mmol) and *t*-butyl acrylate **2a** (110 uL, 0.75 mmol) to afford the title compound in 84% yield (150.4 mg) after silica chromatography (EtOAc/Hex containing 1% Et₃N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 98/2; 90% ee. Product ratio was determined by HPLC, Chiralpak

OJ-H column, IPA/Hex = 10: 90, 1.0 ml/min, $t_{\text{major}} = 13.8$ min, $t_{\text{minor}} = 23.6$ min. $[\alpha]_{\text{D}}^{\text{rt}} = -38.9^{\circ}$ ($c = 1.10$, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3) δ 7.89 (s, 1 H), 7.85-7.78 (m, 3 H), 7.61 (dd, $J = 8.6$ and 1.7 Hz, 1 H), 7.50-7.41 (m, 2 H), 4.53 (d, $J = 8.3$ Hz, 1 H), 4.13-4.04 (m, 1 H), 3.79 (s, 3 H), 2.91 (q, $J = 8.6$ Hz, 1 H), 2.62-2.48 (m, 2 H), 2.45-2.34 (m, 1 H), 1.35 (s, 9 H); ^{13}C NMR (75 MHz, CDCl_3) δ 174.6, 172.5, 138.8, 133.2, 132.9, 128.2, 127.8, 127.5, 125.9, 125.8, 125.7, 124.9, 80.8, 66.9, 59.2, 52.2, 34.2, 27.9; MS (m/z) 356.2 ($\text{M}+1$, 100); HRMS calcd for $\text{C}_{21}\text{H}_{26}\text{NO}_4$ [$\text{M}+\text{H}$] 356.1856. Found 356.1827.

(10): **5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic**

acid dimethyl ester (*exo*-3j): Prepared according to the general procedure with **1a** (105.5 mg, 0.50 mmol) and methyl acrylate **2b** (70 μL , 0.75 mmol) to afford the title compound in 77% yield (114.7 mg) and the undesired *endo*-adduct in 13 % yield (18.9 mg) after silica chromatography (EtOAc/Hex containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 83/17; 91% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{minor}} = 44.2$ min, $t_{\text{major}} = 56.7$ min. $[\alpha]_{\text{D}}^{\text{rt}} = -53.4^{\circ}$ ($c = 0.66$, CH_2Cl_2). ^1H NMR (360 MHz, CDCl_3) δ 7.40 (d, $J = 8.5$ Hz, 2 H), 7.30 (d, $J = 8.5$ Hz, 2 H), 4.41 (d, $J = 8.5$ Hz, 1 H), 4.05 (dd, $J = 8.7$ and 5.4 Hz, 1 H), 3.78 (s, 3 H), 3.65 (s, 3 H), 2.87 (q, $J = 8.6$ Hz, 1 H), 2.55-2.45 (m, 2 H), 2.44-2.35 (m, 1 H); ^{13}C NMR (90 MHz, CDCl_3) δ 174.5, 173.5, 139.7, 133.5, 128.7, 128.4, 65.8, 59.1, 52.4, 52.0, 51.3, 34.2; MS (m/z) 298.1 ($\text{M}+1$, 100); HRMS calcd for $\text{C}_{14}\text{H}_{17}\text{NO}_4\text{Cl}$ [$\text{M}+\text{H}$] 298.0846. Found 298.0834.

5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid

dimethyl ester (*endo*-3j): 67% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 10: 90, 1.0 ml/min, $t_{\text{major}} = 12.4$ min, $t_{\text{minor}} = 34.0$ min. ^1H NMR (360 MHz, CDCl_3) δ 7.28 (s, 4 H), 4.55-4.50 (m, 1 H), 4.03-3.97 (m, 1 H), 3.82 (s, 3 H), 3.36-3.25 (m, 4 H), 2.82 (brs, 1 H), 2.41 (t, $J = 7.5$ Hz, 2 H); ^{13}C NMR (90 MHz, CDCl_3) δ 173.6, 172.7, 137.8, 133.3, 128.3, 128.2, 64.9, 59.7, 52.3, 51.3, 49.4, 33.0; MS (m/z) 320.0 ($\text{M}+\text{Na}$, 100); HRMS calcd for $\text{C}_{14}\text{H}_{17}\text{NO}_4\text{Cl}$ [$\text{M}+\text{H}$] 298.0846. Found 298.0862.

(11): 5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic

acid 4-ethyl ester 2-methyl ester (*exo*-3k): Prepared according to the general procedure with **1a** (105.5 mg, 0.50 mmol) and ethyl acrylate **2c** (80 μL , 0.75 mmol) to afford the title compound in 79% yield (122.1 mg) and the undesired *endo*-adduct in 16 % yield (25.2 mg) after silica chromatography (EtOAc/Hex containing 1% Et_3N). NMR spectroscopic analysis of the crude product indicated the ratio of *exo/endo* was 84/16; 91% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 1: 99, 1.0 ml/min, $t_{\text{minor}} = 31.9$ min, $t_{\text{major}} = 35.4$ min. $[\alpha]_D^{25} = -35.8^\circ$ ($c = 1.00$, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3) δ 7.40 (d, $J = 8.2$ Hz, 2 H), 7.29 (d, $J = 8.2$ Hz, 2 H), 4.39 (d, $J = 8.5$ Hz, 1 H), 4.09 (q, $J = 7.1$ Hz, 2 H), 4.06-4.00 (m, 1 H), 3.77 (s, 3 H), 2.83 (q, $J = 8.6$ Hz, 1 H), 2.55-2.30 (m, 3 H), 1.17 (t, $J = 7.1$ Hz, 3 H); ^{13}C NMR (90 MHz, CDCl_3) δ 174.5, 173.0, 139.9, 133.3, 128.6, 128.3, 65.8, 60.8, 59.0, 52.3, 51.4, 34.1, 14.1; MS

(*m/z*) 312.1 (*M*+1, 100); HRMS calcd for C₁₅H₁₉NO₄Cl [*M*+*H*] 312.1003. Found 312.1018.

5-(4-Chloro-phenyl)-pyrrolidine-2,4-dicarboxylic acid 4-

ethyl ester 2-methyl ester (*endo*-3k): 58% ee. Product ratio was determined by HPLC, Chiralpak AS column, IPA/Hex = 10:90, 1.0 ml/min, *t*_{major} = 10.0 min, *t*_{minor} = 27.9 min. ¹H NMR (360 MHz, CDCl₃) δ 7.28 (s, 4 H), 4.53 (d, *J* = 7.6 Hz, 1 H), 4.00 (t, *J* = 7.8 Hz, 1 H), 3.82 (s, 3 H), 3.80-3.65 (m, 2 H), 3.29 (q, *J* = 7.1 Hz, 1 H), 2.85 (brs, 1 H), 2.45-2.40 (m, 2 H), 0.88 (t, *J* = 7.1 Hz, 3 H); ¹³C NMR (90 MHz, CDCl₃) δ 173.6, 172.3, 137.7, 133.3, 128.35, 128.26, 64.9, 60.4, 59.7, 52.3, 49.5, 33.2, 13.7; MS (*m/z*) 312.0 (*M*+1, 100); HRMS calcd for C₁₅H₁₉NO₄Cl [*M*+*H*] 312.1003. Found 312.0984.

(12): (2*S*,3*S*,4*R*,5*R*)-5-(4-Chloro-phenyl)-pyrrolidine-2,3,4-

tricarboxylic acid trimethyl ester (*exo*-3l): The catalyst was prepared by stirring CuOAc (0.6 mg, 0.005 mmol, 1 mol%) and ligand **L4** (3.0 mg, 0.0055 mmol, 1.1 mol%) in THF (2 mL) for 1 hour at room temperature. Then the mixture was cooled to 0 °C, imine substrate **1a** (105.5 mg, 0.50 mmol), dimethyl maleate **2d** (90 uL, 0.75 mmol, 1.5 equiv.) and triethylamine (8 uL, 0.05 mmol, 10 mol%) were added subsequently and the resulting mixture was stirred at 0 °C overnight. When the reaction was complete as monitored by TLC, NMR spectroscopic analysis of the crude product indicated the ratio

of *exo/endo* was 98/2, the product was purified by column chromatography on silica gel (Hexanes/ethyl acetate/1% triethylamine) to afford the title compound in 87% yield (153.8 mg, Proton NMR spectrum indicated there was about 3% of unidentified isomer); 93% ee. Product ratio was determined by HPLC, Chiralpak AS-H column, IPA/Hex = 10:90, 1.0 ml/min, $t_{\text{major}} = 17.4$ min, $t_{\text{minor}} = 19.9$ min. $[\alpha]_{\text{D}}^{25} = -27.2^{\circ}$ ($c = 0.78$, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3) δ 7.42 (d, $J = 8.5$ Hz, 2 H), 7.29 (d, $J = 8.5$ Hz, 2 H), 4.66 (d, $J = 8.0$ Hz, 1 H), 4.35 (d, $J = 5.6$ Hz, 1 H), 3.80 (s, 3 H), 3.72 (s, 3 H), 3.65 (s, 3 H), 3.62 (dd, $J = 8.8$ and 5.6 Hz, 1 H), 3.20 (t, $J = 8.4$ Hz, 1 H), 2.58 (br, 1 H); ^{13}C NMR (75 MHz, CDCl_3) δ 173.4, 171.9, 171.7, 140.4, 133.8, 129.0, 128.8, 64.0, 62.0, 54.7, 53.0, 52.8, 52.5, 50.0; MS (m/z) 356.1 ($M+1$, 100); HRMS calcd for $\text{C}_{16}\text{H}_{19}\text{NO}_6\text{Cl}$ [$M+H$] 356.0895. Found 356.0894.

(13) (2*S*,3*S*,4*R*,5*R*)-5-(4-Chloro-phenyl)-1-(toluene-4-

sulfonyl)-pyrrolidine-2,3,4-tricarboxylic acid trimethyl ester (*exo*-4): The compound **31** (130.0 mg, 0.37 mmol) was dissolved in 2 mL of methylene chloride, *p*-toluenesulfonyl chloride (106.0 mg, 0.56 mmol) and triethyl amine (0.15 mL, 1.10 mmol) were added subsequently and the resulting mixture was stirred for 48 hours at room temperature. The crude product was purified by column chromatography on silica gel (Hexanes/ethyl acetate) to afford the title compound in 73% yield (136.2 mg); ^1H NMR (360 MHz, CDCl_3) δ 7.58-7.50 (m, 4 H), 7.28-7.20 (m, 4 H), 5.09 (d, $J = 6.4$ Hz, 1 H), 4.82 (d, $J = 5.0$ Hz, 1 H), 3.89 (s, 3 H), 3.62 (s, 3 H), 3.53 (dd, $J = 6.6$ and 5.1 Hz, 1 H), 3.49 (s, 3 H), 3.31 (t, $J = 8.4$ Hz, 1 H), 2.41 (s, 3 H); ^{13}C NMR (90 MHz, CDCl_3) δ 171.4,

169.4, 169.2, 144.0, 138.3, 134.5, 133.8, 129.4, 128.8, 128.5, 127.8, 65.1, 62.5, 53.9, 53.1, 52.7, 52.3, 48.2, 21.5.

Recrystallization of compound *exo-4* from hexanes afforded suitable crystals for X-ray analysis: C₂₃H₂₄ClNO₈S, MW = 509.94, orthorhombic, space group *P*2(1)2(1)2(1), Mo K α , final R indices ($I > 2\sigma(I)$), $R_1 = 0.0367$, $wR_2 = 0.0836$, $a = 9.422(3)$ Å, $b = 9.507(3)$ Å, $c = 26.579(7)$ Å, $\beta = 90^\circ$, $V = 2381.0(11)$ Å³, $T = 98(2)$ K, $Z = 4$, reflections collected/unique 22203/5904 ($R_{\text{int}} = 0.0378$), no observation ($I > 2\sigma(I)$) 5590, parameters 311, Flack parameters 0.02(4), CCDC 268934

Figure: X-ray structure of *exo-4*

NOESY spectrum of compound *exo-3a* and *exo-3l*:

Reference:

- [1] Grigg, R.; Guaratne, H. Q. N.; Kemp, J. *J. Chem. Soc., Perkin Trans. 1*, **1984**, 41.
- [2] Longmire, J. M.; Wang, B.; Zhang, X. *J. Am. Chem. Soc.* **2002**, *124*, 13400.