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Dimeric (salen)Al Complexes Display Expanded Scope in the Conjugate Cyanation of α,β-Unsaturated Imides

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General: All reactions were carried out under an inert atmosphere of N_2. Unless otherwise noted, all reagents were purchased from Aldrich or Strem and used without further purification. Solvents were purified and dried using standard methods: toluene and benzene were distilled from sodium; THF was distilled from sodium/benzophenone ketyl; isopropanol was distilled from magnesium onto activated 3Å molecular sieves. Trimethylsilylcyanide was distilled prior to use. CAUTION!!! Trimethylsilyl cyanide (TMSCN) is a severe poison and should only be used in a hood with good ventilation. When concentrating solutions with either TMSCN or HCN, a potassium carbonate trap was used to remove any residual cyanide. Liquid reagents were transferred with stainless steel syringes or canula. Flash chromatography was performed using silica gel 60 (230–400 mesh) from EM Science.

Instrumentation: All ^{1}H NMR and ^{13}C NMR spectra were recorded either on Inova 600 or on Varian Mercury-400 spectrometers at ambient temperature. IR spectra were recorded on a Matteson FTIR 3000. Optical rotations were measured using a 2-mL cell with a 1 dm path length on a Jasco DIP 370 digital polarimeter. The mass spectroscopic data were obtained at the Harvard University mass spectrometry facility. Chiral GC analysis was performed on a Hewlett–Packard 5890 gas chromatograph. Chiral HPLC analysis was performed on a Hewlett–Packard 1050 HPLC.

Experimental: Catalyst **1** was prepared as described previously.[i] Aluminium complexes **2a-g** were prepared following a similar procedure starting from the corresponding bis-salen ligands, the synthesis of which has been already described[ii] (Note: the ^{1}H NMR spectrum of the dimeric (salen)Al complexes were usually similar to those of the corresponding ligands but substantially broaden with no reliable integration due to the 5/2 spin value of aluminium). All *α,β*-unsaturated imides were prepared by Horner-Wadsworth-Emmons olefinations according to literature procedures.[iii, iv, v] Data for previously unreported imides **4f**, **4j-n** and **6b-c** as well as the cyanation products **5f**, **5j-n**, **7a-c** are described below.

2a: IR (neat) 3363.4, 2959.4, 1633.2, 1561.6 cm^{-1}; ESI/MS for $C_{69}H_{92}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1204.2 (100%).

2b: IR (neat) 3433.2, 2955.5, 1633.2, 1559.6 cm^{-1}; ESI/MS for $C_{70}H_{94}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1218.2 (100%).

2c: IR (neat) 3357.4, 2953.1, 1633.4, 1559.6 cm^{-1}; ESI/MS for $C_{71}H_{96}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1232.2 (100%).

2d: IR (neat) 3450, 2932.3, 1641.9, 1558.5 cm^{-1}; ESI/MS for $C_{72}H_{98}Al_2Cl_2N_4O_8$ [M – 2Cl + CH_3CN + HCO_2H + HCO_2^-]$^+$: 1333.4 (100%).

2e: IR (neat) 3503, 2957, 1746.2, 1634.4, 15570 cm^{-1}; ESI/MS for $C_{73}H_{100}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1260.3 (100%).

2f: IR (neat) 3430.1, 2951.4, 2866.6, 1633.5, 1559.5, 1357.6 cm^{-1}; ESI/MS for $C_{74}H_{102}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1274.4 (100%).

2g: IR (neat) 3455, 2954, 1633, 1559, 1201 cm^{-1}; ESI/MS for $C_{76}H_{106}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1302.5 (100%).

Synthesis of L-3:
1,3-phenylenediacetic acid (1.00 mmol) was added to a solution of 2-tert-butyl-6-((*E*)-((1*R*,2*R*)-2-((*E*)-3,5-di-tert-butyl-2-hydroxybenzylideneamino)cyclohexylimino)methyl) benzene-1,4-diol (2.00 mmol),[2, vi] 1,3-diisopropylcarbodiimide (2.05 mmol) and 4-(dimethylamino)-pyridine (0.20 mmol) in CH_2Cl_2 (10 mL) at 0°C. The reaction was stirred for 8 hours at ambient temperature, diluted with an additional 50 mL of CH_2Cl_2, washed with 1 N HCl_{aq}, saturated potassium bicarbonate and brine. The solution was concentrated under vaccum and purified by flash chromatography (1:9 ethyl acetate/hexanes) to afford **L-3** as a yellow foam in 74% yield.

L-3: R_f = 0.27 (1:9 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) *d* 8.30 (s, 2H), 8.18 (s, 2H), 7.35-7.30 (m, 6H), 6.98 (d, *J* 2.4 Hz, 2H), 6.92 (d, *J* 2.4 Hz, 2H), 6.74 (d, *J* 2.4 Hz, 2H), 3.81 (s, 4H), 3.31 (bm, 4H), 1.93-1.28 (bm, 16H), 1.41 (s, 18H), 1.37 (s, 18H), 1.24 (s, 18H); ^{13}C (100 MHz, $CDCl_3$) *d* 170.5, 166.1, 164.8, 158.4, 158.2, 141.8, 140.2, 138.8, 136.6, 134.2, 130.6,129.3, 128.5, 127.1, 126.2, 122.9, 121.5, 118.4, 117.9, 72.7, 72.4, 41.4, 35.2, 35.1, 34.3, 33.3, 31.6, 31.5, 29.7, 29.5, 29.3, 24.5, 17.9; IR (neat) 2957.2, 2836.8, 1758.7, 1629.6, 1439.0, 1119.2 cm^{-1}; ESI/MS for $C_{74}H_{98}N_4O_8$ [M + H]$^+$: 1172.8 (9%).

3: IR (neat) 3450, 2954, 1742, 1652, 1257 cm^{-1}; ESI/MS for $C_{74}H_{94}Al_2Cl_2N_4O_8$ [M – 2Cl + HCO_2^-]$^+$: 1266.1 (100%).

Previously unreported α,β-unsaturated imides.

(*E*)-*N*-(3-cyclohexylacryloyl)benzamide (4f): R_f = 0.39 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.78 (bs, 1H), 7.86 (d, *J* 7.2 Hz, 2H), 7.60 (t, *J* 8 Hz, 1H), 7.48 (t, *J* 7.6 Hz, 2H), 7.15 (m, 2H), 2.24 (m, 1H), 1.86-1.66 (bm, 5H), 1.36-1.16 (m, 5H); ^{13}C (100 MHz, $CDCl_3$) δ 168.2, 166.1, 133.4, 133.3, 129.2, 128.0, 120.6, 41.2, 31.2, 26.1, 25.9; IR (neat) 3274, 2925, 1723, 1506 cm^{-1}; ESI/MS for $C_{16}H_{19}NO_2$ $[M + Na]^+$: 280.1 (100%).

(*E*)-*N*-(4-phenylbut-2-enoyl)benzamide (4j): R_f = 0.28 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.69 (bs, 1H), 7.86 (d, *J* 7.2 Hz, 2H), 7.61 (t, *J* 7.6 Hz, 1H), 7.48 (t, *J* 8 Hz, 2H), 7.36-7.16 (m, 7H), 3.63 (d, *J* 7.2 Hz, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 167.5, 166.0, 149.8, 137.9, 133.5, 133.2, 129.2, 129.0, 128.9, 127.9, 126.9, 123.8, 39.2; IR (neat) 3274, 1723, 1700, 1506 cm^{-1}; ESI/MS for $C_{17}H_{15}NO_2$ $[M + Na]^+$: 288.1 (100%).

(*E*)-ethyl 6-benzamido-6-oxohex-4-enoate (4k): R_f = 0.14 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.12 (bs, 1H), 7.89 (d, *J* 7.2 Hz, 2H), 7.57 (t, *J* 7.6 Hz, 1H), 7.48 (t, *J* 7.2 Hz, 2H), 7.16 (m, 2H), 4.14 (q, *J* 7.2 Hz, 2H), 2.61 (m, 2H), 2.51 (m, 2H), 1.25 (t, *J* 7.6 Hz, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 172.6, 167.8, 166.2, 133.4, 133.1, 129.1, 128.1, 123.8, 60.9, 32.7, 27.9, 14.4; IR (neat) 3276, 2986, 1732, 1707, 1506 cm^{-1}; ESI/MS for $C_{15}H_{17}NO_4$ $[M + Na]^+$: 298.1 (100%).

(*E*)-*N*-(5-(methoxymethoxy)pent-2-enoyl)benzamide (4l): R_f = 0.11 (1:3 ethyl acetate/hexanes); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.05 (bs, 1H), 7.89 (d, *J* 7.8 Hz, 2H), 7.59 (t, *J* 7.5 Hz, 1H), 7.49 (t, *J* 7.8 Hz, 2H), 7.26-7.18 (m, 2H), 4.63 (s, 2H), 3.70 (dd, *J* 6.3 Hz, 5.9 Hz, 2H), 3.36 (s, 3H), 2.60 (dd, *J* 6.3 Hz, 5.9 Hz, 2H); ^{13}C (125 MHz, $CDCl_3$) δ 167.4, 165.9, 147.9, 133.1, 132.9, 128.8, 128.3, 127.9, 127.7, 124.3, 96.4, 65.8, 55.2, 33.0; IR (neat) 3282, 1728, 1678, 1483 cm^{-1}; ESI/MS for $C_{14}H_{17}NO_4$ $[M + Na]^+$: 286.1 (100%).

(*E*)-*N*-(5-(tert-butyldiphenylsilyloxy)pent-2-enoyl)benzamide (4m): R_f = 0.33 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.69 (bs, 1H), 7.89 (d, *J* 8 Hz, 2H), 7.72-7.38 (m, 14H), 7.21 (dt, *J* 15.6 Hz, *J* 3.2 Hz, 1H), 4.44 (m, 2H), 1.12 (s, 9H); ^{13}C (100 MHz, $CDCl_3$) δ 167.5, 165.8, 149.5, 135, 8, 133.4, 133.3, 130.1, 129.2, 128.1, 128.0, 121.3, 63.6, 27.0, 19.5; IR (neat) 3271, 2857, 1720, 1676, 1506 cm^{-1}; ESI/MS for $C_{27}H_{29}NO_3Si$ $[M + Na]^+$: 466.2 (100%).

(*E*)-benzyl 5-benzamido-5-oxopent-3-enylcarbamate (4n): R_f = 0.36 (1:1 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.82 (bs, 1H), 7.86 (bd, *J* 7.6 Hz, 2H), 7.59 (bt, *J* 7.2 Hz, 1H), 7.48 (bt, *J* 8 Hz, 2H), 7.34-7.11 (bm, 7H), 5.09 (s, 2H), 5.02 (bs, 1H), 3.40 (m, 2H), 2.52 (m, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 167.3, 166.1, 156.6, 147.4, 136.7, 133.5, 133.1, 129.2, 128.8, 128.4, 128.3, 128.0, 125.2, 67.00, 39.7, 33.3; IR (neat) 3350, 1701, 1685, 1257 cm^{-1}; ESI/MS for $C_{20}H_{20}N_2O_4$ $[M + Na]^+$: 375.1 (100%).

(*E*)-*N*-(3,4,4-trimethylpent-2-enoyl)benzamide (6b): R_f = 0.44 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.19 (bs, 1H), 7.92 (d, *J* 7.6 Hz, 2H),

7.56 (t, *J* 7.6 Hz, 1H), 7.47 (t, *J* 7.6 Hz, 2H), 6.98 (d, *J* 1.2 Hz, 1H), 2.19 (d, *J* 1.2 Hz, 3H), 1.18 (s, 9H); ^{13}C (100 MHz, $CDCl_3$) δ 170.3, 168.9, 166.2, 133.6, 133.1, 129.0, 128.1, 115.4, 38.8, 28.8, 16.7; IR (neat) 3266, 2969, 1703, 1667, 1471 cm^{-1}; ESI/MS for $C_{15}H_{19}NO_2$ $[M + Na]^+$: 268.1 (100%).

***N*-(2*E*,4*E*)-hexa-2,4-dienoylbenzamide (6c):** R_f = 0.31 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.10 (bs, 1H), 7.86 (d, *J* 7.2 Hz, 2H), 7.62 (t, *J* 7.2 Hz, 1H), 7.51 (t, *J* 8 Hz, 2H), 7.44-7.34 (m, 5H), 4.44 (dd, *J* 9.2 Hz, 5.2 Hz, 1H), 3.77 (dd, *J* 18.4 Hz, 9.2 Hz, 1H), 3.59 (dd, *J* 18.4 Hz, 5.2 Hz, 1H); ^{13}C (125 MHz, $CDCl_3$) δ 168.1, 165.8, 147.2, 141.2, 133.1, 133.0, 130.4, 128.9, 127.8, 120.3, 18.8; IR (neat) 3291, 2930, 1698, 1669, 1597 cm^{-1}; ESI/MS for $C_{13}H_{14}NO_2$ $[M + H]^+$: 216.3 (100%).

Representative procedure for the conjugate cyanation of α,β-unsaturated imides.

Aluminium complex **2e** (16 mg, 0.0125 mmol, 2.5 mol% in catalyst, 5 mol% in [Al]), imide **4e** (115 mg, 0.5 mmol) and 1,3-di-*tert*-butyl-2-methoxy-5-methylbenzene as internal standard (10μL) were combined in a 4 mL vial equipped with a sure sealed rubber cap. The system was purged by three successive vaccum/N_2 sequences and finally placed under a N_2 atmosphere. MTBE (100 μL) and TMSCN (500 μL, 3.25 mmol) were successively added and the vial was directly placed into an oil bath preheated at 50°C. After 15 minutes, *i*-PrOH (250 μL, 3.25 mmol) was added slowly. The reaction mixture was stirred at 50°C for the specified amount of time (see Full Text for details). Volatiles were removed in vaccuo with a K_2CO_3 trap. The residue was dissolved in ethyl acetate/hexanes (1:3), filtered through a short plug of silica or Celite® (pasteur pipette) to remove the catalyst and conversion was assessed by ^{1}H NMR spectroscopy. Purification was achieved by flash chromatography (typically, 1:3 ethyl acetate/hexanes, unless otherwise noted) to afford the cyanation product as either white powders or oils.

(*S*)-*N*-(3-cyano-3-cyclohexylpropanoyl)benzamide (5f): R_f = 0.19 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.39 (bs, 1H), 7.93 (d, *J* 8 Hz, 2H), 7.61 (t, *J* 7.6 Hz, 1H), 7.53 (t, *J* 7.6 Hz, 2H), 3.44 (dd, *J* 18.4 Hz, 9.6 Hz, 2H), 3.30 (dd, *J* 18.4 Hz, 4.4 Hz, 2H), 3.05 (m, 1H), 1.94-1.61 (bm, 5H), 1.23 (bm, 5H); ^{13}C (100 MHz, $CDCl_3$) δ 173.6, 166.2, 133.9, 132.3, 129.4, 128.1, 120.9, 39.3, 38.4, 33.2, 31.4, 29.6, 26.2, 26.1, 26.0; IR (neat) 2929.0, 1711.3, 1677.2, 1468.3, 1245.4 cm^{-1}; ESI/MS for $C_{17}H_{20}N_2O_2$ $[M + Na]^+$: 307.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 21.2 (minor), 22.1 (major) with (*R*,*R*)-**2e**.

(*R*)-*N*-(3-cyano-4-phenylbutanoyl)benzamide (5j): R_f = 0.10 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.07 (bs, 1H), 7.89 (d, *J* 7.2 Hz, 2H), 7.63 (bt, 1H), 7.53 (bt, 2H), 7.36-7.27 (m, 5H), 3.49-3.30 (m, 3H), 3.07 (dd, *J* 13.6 Hz, 7.2 Hz, 2H), 3.00 (dd, *J* 13.6 Hz, 7.2 Hz, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 172.7, 165.9, 136.5, 133.9, 132.2, 129.4, 129.3, 129.1, 127.9, 127.8, 121.3, 39.8, 37.9, 28.9; IR (neat) 3228.3, 1714.3, 1688.4, 1469.4, 1242.6 cm^{-1}; ESI/MS for $C_{18}H_{16}N_2O_2$ $[M + Na]^+$: 315.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 32.6 (minor), 33.8 (major) with (*R*,*R*)-**2e**.

(*R*)-ethyl 6-benzamido-4-cyano-6-oxohexanoate (5k): R_f = 0.06 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.61 (bs, 1H), 7.92 (d, *J* 7.6 Hz, 2H), 7.59 (t, *J* 7.6 Hz, 1H), 7.52 (t, *J* 8 Hz, 2H), 4.13 (q, *J* 7.6 Hz, 2H), 3.49-3.21 (m, 3H), 2.58 (m, 2H), 2.02 (m, 2H), 1.25 (t, *J* 7.6 Hz, 3H); ^{13}C (100 MHz, $CDCl_3$) δ 173.1, 172.2, 166.3, 133.8, 132.2, 129.3, 128.2, 121.1, 61.1, 40.5, 31.6, 27.1, 26.4, 14.4; IR (neat) 3286.6, 1720.1, 1668.0, 1470.1, 1243.6 cm^{-1}; ESI/MS for $C_{16}H_{18}N_2O_4$ $[M + Na]^+$: 325.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 51.8 (minor), 52.8 (major) with (*R,R*)-**2e**.

(*R*)-*N*-(3-cyano-5-(methoxymethoxy)pentanoyl)benzamide (5l): R_f = 0.08 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.79 (bs, 1H), 7.96 (d, *J* 8 Hz, 2H), 7.60 (t, *J* 8.4 Hz, 1H), 7.52 (t, *J* 8 Hz, 2H), 4.61 (s, 2H), 3.71 (m, 2H), 3.52-3.32 (m, 5H), 3.35 (s, 3H), 1.98 (m, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 173.6, 166.4, 133.8, 132.2, 129.3, 128.3, 121.3, 96.7, 64.4, 55.6, 40.4, 32.0, 24.2; IR (neat) 3286.1, 2935.1, 1715.7, 1682.1, 1470.1, 1244.3 cm^{-1}; ESI/MS for $C_{15}H_{18}N_2O_4$ $[M + Na]^+$: 313.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 45.7 (minor), 46.3 (major) with (*R,R*)-**2e**.

(*R*)-*N*-(5-(tert-butyldiphenylsilyloxy)-3-cyanopentanoyl)benzamide (5m): R_f = 0.13 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.65 (bs, 1H), 7.83 (d, *J* 7.2 Hz, 2H), 7.71-7.62 (m, 5H), 7.53 (t, *J* 8 Hz, 2H), 7.46-7.38 (m, 6H), 3.86 (ddd, *J* 4 Hz, 2.8 Hz, 3.2 Hz, 2H), 3.52-3.35 (m, 3H), 1.09 (s, 9H); ^{13}C (100 MHz, $CDCl_3$) δ 172.2, 165.7, 135.8 (2C), 133.8, 132.7, 132.6, 132.4, 130.2, 130.1, 129.4, 129.2, 128.0, 127.9, 120.2, 63.1, 37.1, 30.0, 27.0, 19.5; IR (neat) 3281.9, 2958.7,2931.8, 2858.5, 1714.0,1687.5, 1662.5, 1471.1, 1113.2 cm^{-1}; ESI/MS for $C_{28}H_{30}N_2O_3Si$ $[M + Na]^+$: 493.2 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 16.8 (minor), 17.8 (major) with (*R,R*)-**2e**.

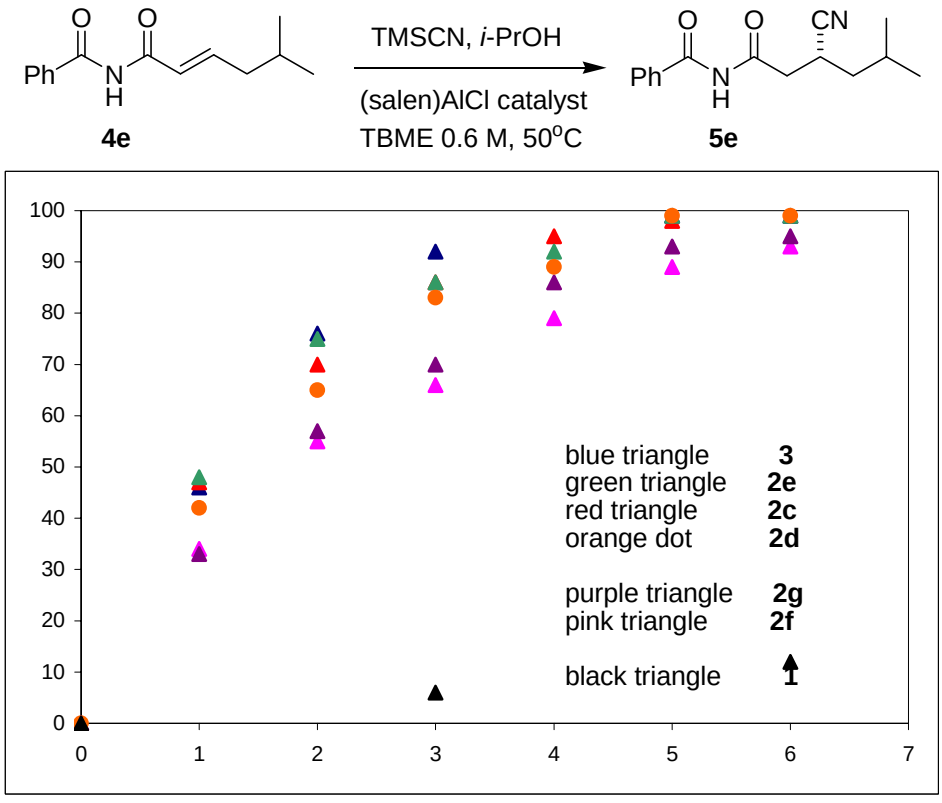
(*R*)-benzyl 5-benzamido-3-cyano-5-oxopentylcarbamate (5n): R_f = 0.33 (1:1 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.56 (bs, 1H), 7.90 (d, *J* 7.6 Hz, 2H), 7.57 (t, *J* 7.2 Hz, 1H), 7.49 (t, *J* 8 Hz, 2H), 7.33-7.25 (bm, 5H), 5.29 (bt, 1H), 5.09 (bs, 2H), 3.46-3.19 (m, 5H), 1.91 (bm, 2H); ^{13}C (100 MHz, $CDCl_3$) δ 173.0, 166.4, 156.8, 136.6, 133.8, 129.3, 128.8, 128.4, 128.3, 121.4, 67.1, 40.3, 38.8, 32.2, 24.5; IR (neat) 3359.9, 1713.2, 1693.7, 1428.4 cm^{-1}; ESI/MS for $C_{21}H_{19}N_3O_3$ $[M + Na]^+$: 384.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 88:12, 1.2 ml/min, retention time: 50.3 (minor), 52.0 (major) with (*R,R*)-**2e**.

(*S*)-*N*-(3-cyano-3-phenylpropanoyl)benzamide (7a): R_f = 0.29 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.10 (bs, 1H), 7.86 (d, *J* 7.2 Hz, 2H), 7.62 (t, *J* 7.2 Hz, 1H), 7.51 (t, *J* 8 Hz, 2H), 7.44-7.34 (m, 5H), 4.44 (dd, *J* 9.2 Hz, 5.2 Hz, 1H), 3.77 (dd, *J* 18.4 Hz, 9.2 Hz, 1H), 3.59 (dd, *J* 18.4 Hz, 5.2 Hz, 1H); ^{13}C (100 MHz, $CDCl_3$) δ 172.2, 134.8, 133.9, 132.1, 129.5, 129.4, 128.7, 128.0, 127.8, 120.5, 43.8, 32.6; IR (neat) 3292.7, 2360.2, 2342.1, 2331.5, 1714.9, 1685.8, 1243.6 cm^{-1}; ESI/MS for $C_{17}H_{14}N_2O_2$ $[M + Na]^+$: 301.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 34.8 (major), 35.4 (minor) with (*R,R*)-**2e**.

(*S*)-*N*-(3-cyano-3,4,4-trimethylpentanoyl)benzamide (7b): R_f = 0.21 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.11 (bs, 1H), 7.92 (d, *J* 8 Hz, 2H), 7.58 (t, *J* 7.6 Hz, 1H), 7.52 (t, *J* 7.6 Hz, 2H), 3.54 (d, *J* 16.8 Hz, 1H), 3.19 (d, *J* 16.8 Hz, 1H), 1.48 (s, 3H), 1.09 (s, 9H); ^{13}C (100 MHz, $CDCl_3$) δ 172.9, 166.2, 160.1, 133.8, 132.6, 129.4, 128.0, 123.3, 41.6, 36.8, 25.8, 19.1; IR (neat) 3294.6, 2969.3, 1709.9, 1678.4, 1465.4, 1242.1 cm^{-1}; ESI/MS for $C_{16}H_{20}N_2O_4$ $[M + H]^+$: 273.1 (100%); HPLC Pirkle Leucine, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 16.4 (minor), 28.9 (major) with (*R*,*R*)-**3**.

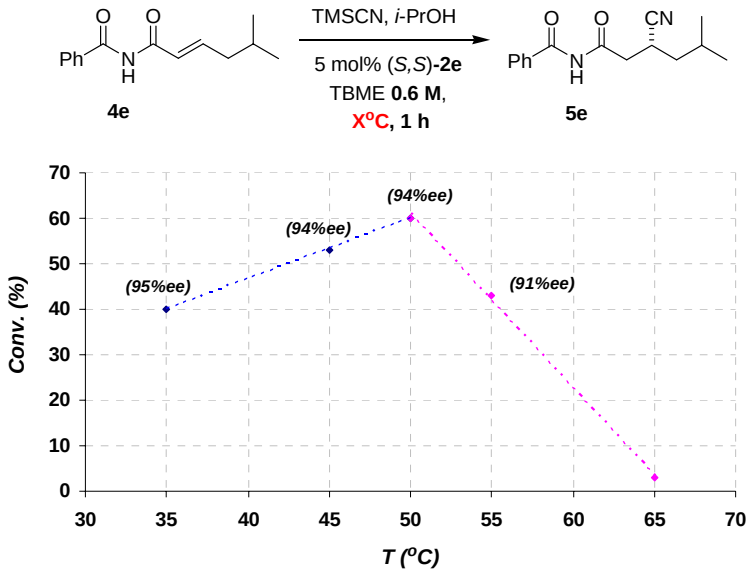
(*S*,*E*)-*N*-(3-cyanohex-4-enoyl)benzamide (7c): R_f = 012 (1:3 ethyl acetate/hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.70 (bs, 1H), 7.84 (d, *J* 7.2 Hz, 2H), 7.62 (t, *J* 7.2 Hz, 1H), 7.53 (t, *J* 7.6 Hz, 2H), 5.95 (m, 1H), 5.49 (m,1H), 3.82 (m, 1H), 3.49 (dd, *J* 18.0 Hz, *J* 6.4 Hz, 1H), 3.46 (dd, *J* 18.4 Hz, *J* 6.4 Hz, 1H), 1.74 (d, *J* 6.4 Hz, 3H), 1.09 (s, 9H); ^{13}C (100 MHz, $CDCl_3$) δ 171.9, 165.7, 133.9, 132.3, 130.9, 129.4, 127.9, 123.6, 120.1, 41.5, 29.4, 17.9; IR (neat) 3282.4, 1715.3, 1687.0, 1470.3, 1242.5 cm^{-1}; ESI/MS for $C_{14}H_{14}N_2O_2$ $[M + Na]^+$: 265.1 (100%); HPLC OB, Hexanes:EtOH = 93:07, 1.0 ml/min, retention time: 34.5 (minor), 38.3 (major) with (*R*,*R*)-**3**.

Comparative study on the reactivity of (salen)Al complexes 1, 2c-g and 3 for the catalytic conjugate cyanation of imide 4e.



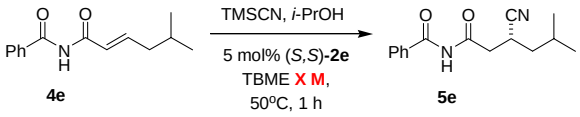
see also Figure 2 in the article.

Effect of temperature on the activity and the enantioselectivity of the catalyst.



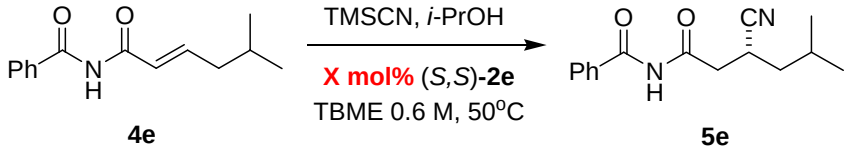
Reactions were carried out using catalyst **2e** and imide **4e**, following the standard procedure described above. After 1 h the reaction mixture was diluted with 1 mL of CH_2Cl_2 and then worked-up as previously described. At temperatures below 35°C, reproducibility of the reaction becomes a problem, especially with the monomeric (salen)AlCl complex **1**. Between 35 to 50°C, there is a net increase in activity without substantial loss of enantioselectivity. Above 50°C, both rate and selectivity are decreased. Therefore, all reactions were run at 50°C using a *J-KEM Scientific* thermo-control system.

Effect of concentration on the catalyst performance.



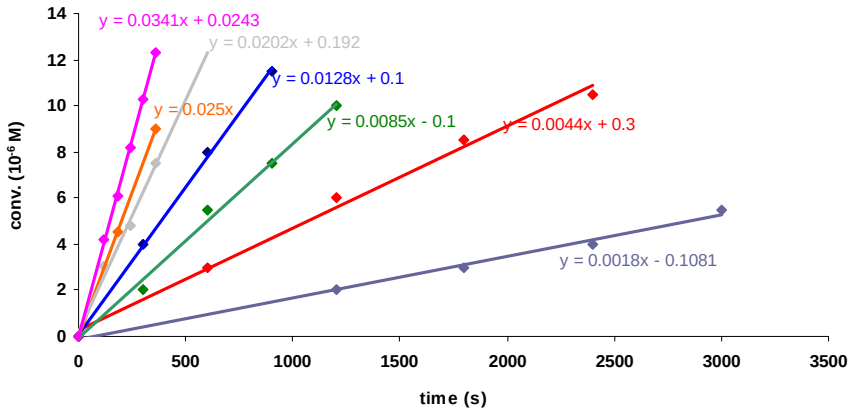
Concentration	conv. (%)	ee (%)
0.4 M	21	94
0.5 M	51	94
0.6 M	73	94
0.67 M (neat in TBME)	60	91

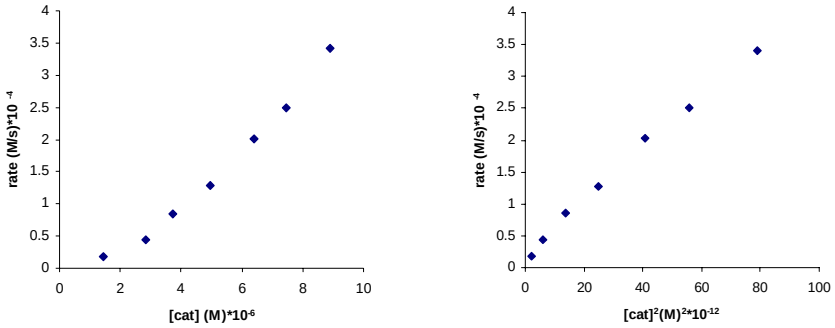
Initial rate kinetic experiments.



Reactions were carried out as described in the typical procedure on a 0.5 mmol scale using model substrate **4e**, catalyst (*R,R*)-**2e** at concentration ranging from 2.5 to 17.5 mol% (in [Al]) and 1,3-di-*tert*-butyl-2-methoxy-5-methylbenzene as internal standard (10μL). To calibrate the ratio '*substrate / internal standard*' by ^{1}H NMR spectroscopy, a first aliquot (15 μL) was taken before the addition of *i*-PrOH (t = 0 min) and quenched in 1 mL of $CDCl_3$. After addition of i-PrOH, reaction progress was monitored by ^{1}H NMR spectroscopy on the first 20% of the reaction by taking aliquots (15 μL) quenched by dilution in 1mL of $CDCl_3$. Integration of the consumption of starting material relative to the internal standard or of the formation of product relative to the internal standard gave similar results.

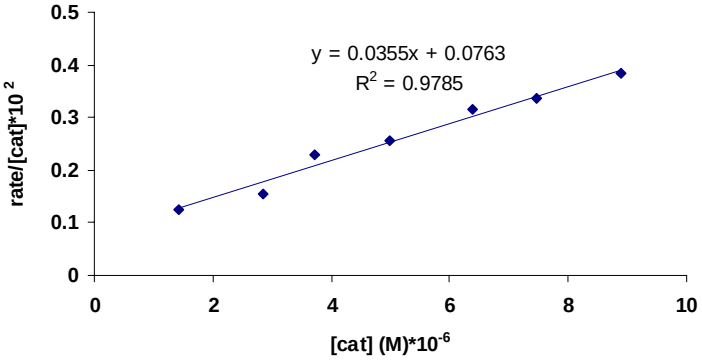
initial rate (M/s)×10^{-4}	**[catalyst] (M×10^{-6})**
0.18	1.42435
0.44	2.8487
0.85	3.7305
1.28	4.974
2.02	6.3984
2.5	7.461
3.41	8.8854





$$\text{rate} = k_1.[\text{catalyst}] + k_2.[\text{catalyst}]^2$$

$$\text{rate}/[\text{catalyst}] = k_1 + k_2.[\text{catalyst}]$$



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