

Supporting Information

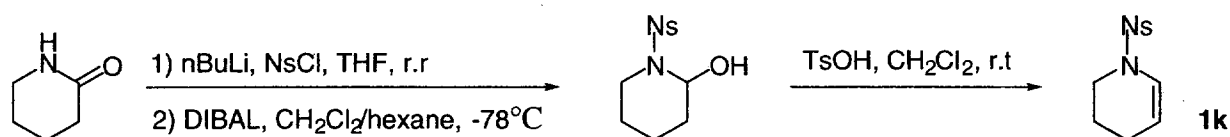
Novel Multi-Action of Zr-Catalyst: One-Pot Synthesis of β -Cyanohydrins from Olefins

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General: NMR spectra were recorded on a JEOL JNM-LA500 spectrometer, operating at 500 MHz for ^1H NMR, 125.65 MHz for ^{13}C NMR, and 202 MHz for ^{31}P NMR. Chemical shifts were reported downfield from TMS ($= 0$) for ^1H NMR. For ^{13}C NMR, chemical shifts were reported in the scale relative to the solvent used as internal reference. ^{31}P NMR were carried out with phosphoric acid (85%) as external standard. Optical rotations were measured on a JASCO P-1010 polarimeter. Column chromatography was performed with silica gel Merck 60 (230-400 mesh ASTM). The enantiomeric excess (ee) was determined by HPLC analysis. HPLC analysis was performed on JASCO HPLC systems: pump, 880-PU or PU-980; detector, 875-UV or UV-970, measured at 254 nm; column, DAICEL CHIRALPAK AS; mobile phase, hexane-2-propanol. In general, reactions were carried out in dry solvents under an argon atmosphere, unless otherwise noted. Tetrahydrofuran (THF) and toluene were distilled from sodium benzophenone ketyl. Dichloromethane (CH_2Cl_2) and dichloroethane ($\text{ClCH}_2\text{CH}_2\text{Cl}$) were distilled from calcium hydride. Other reagents were purified by usual methods.

Materials: The diol ligand of **3** was synthesized according to the known procedure using Grignard reagent.¹ The starting olefins **1e**² and **1f**³ were synthesized according to the reported procedures. β -Cyanohydrins **1a**, **1b**⁴ and **2o**⁵ are known compounds.

Synthesis of the protected enamide 1k: **1k** was synthesized following the procedure reported by Somfai⁶ as shown in the scheme below.



1-(4'-nitrobenzenesulfonyl)-piperidin-2-ol: *n*-Butyllithium (31.3 mL of a 1.6 M solution in hexane) was added to 2-piperidone (4.96 g, 50 mmol) in THF (150 mL) at 0 °C. After 35 min, 4-nitrobenzenesulfonyl chloride (12.2 g, 55 mmol) was added, and the mixture was stirred for further 50 min. Concentration under reduced pressure, and trituration with ether followed by filtration gave the crude product (12.67 g). To a solution of the crude product in CH_2CH_2 (180 mL), DIBAL (45 mL, 45 mmol, 1.0 M in hexane) was added at -78 °C and the mixture was stirred at -78 °C for 30 min. The reaction was quenched by the addition of methanol, and then the whole was poured into a saturated aqueous solution of Rochelle salt. The aqueous phase was extracted once with methylene chloride, and the combined organic phases were dried over Na_2SO_4 . Evaporation followed by recrystallization (CH_2CH_2 /hexane) yielded sulfonamide as an orange powder (7.16 g, 50 % (2 steps)). ^1H NMR (CDCl_3) δ 1.49-1.88 (m, 6H), 2.29 (d, $J = 4.3$ Hz, 1H), 3.11 (dt, $J = 2.8, 12.2$ Hz, 1H), 2.58-3.64 (m, 1H), 5.61-5.64 (m, 1H), 8.04 (d, $J = 9.2$ Hz, 2H), 8.34 (d, $J = 9.2$ Hz, 2H); ^{13}C NMR (CDCl_3) δ 17.0, 24.8, 31.7, 40.6, 100.6, 124.2, 128.7, 142.1, 145.8; IR (KBr) 3510, 1525, 1346, 1165 cm^{-1} ; MS m/z 286 (M^+), 268 ($\text{M}^+ - \text{OH}_2$), 186 (Ns); HRMS Calcd for $\text{C}_{11}\text{H}_{14}\text{N}_2\text{O}_5\text{S}$ (M^+) 286.0623. Found 286.0622.

1-(4'-nitrobenzenesulfonyl)-1,2,3,4-tetrahydro-pyridine 1k: To a solution of the sulfonamide (1.69 g, 5.9 mmol) in CH_2CH_2 (35 mL) was added $\text{TsOH} \cdot \text{H}_2\text{O}$ (337 mg, 17.7 mg). The reaction mixture was stirred at room temperature for 5 h and the treated with K_2CO_3 . The mixture was stirred for further 30 min. After filtration, purification by SiO_2 column chromatography and recrystallization gave the enamide **1k** as yellow crystals (1.24 g, 78 %). ^1H NMR (CDCl_3) δ 1.04-1.09 (m, 2H), 1.36-1.39 (m, 2H), 2.98-3.00 (m, 2H), 4.64 (dt, $J = 3.7, 8.2$ Hz, 1H), 6.58 (dt, $J = 2.2, 8.2$ Hz, 1H), 7.35 (d, $J = 8.8$ Hz, 2H),

7.55 (d, $J = 8.8$ Hz, 2H); ^{13}C NMR (CDCl_3) δ 20.8, 20.9, 44.0, 109.1, 124.1, 124.8, 127.9, 143.6, 146.9; IR (KBr) 1525, 1344, 1171 cm^{-1} ; MS m/z 269 ($\text{M}^+ + 1$), 268 (M^+), 222 ($\text{M}^+ - \text{NO}_2$), 186 (Ns); HRMS Calcd for $\text{C}_{11}\text{H}_{14}\text{N}_2\text{O}_5\text{S}$ (M^+) 268.0518. Found 286.0517.

Synthesis of the chiral ligand 14: To a THF solution of *o*-ethylphenylmagnesium bromide (1M in THF) (40.6 mmol), the known diester⁷ (2.0 g, 8.1 mmol) was added under ice bath, and the whole was stirred at reflux temperature for 2 h. After cooling to r.t., the reaction was further stirred for 12 h. Adding saturated aqueous solution of NH_4Cl , usual workup and purification by SiO_2 column chromatography gave **14** (2.38 g, 48% yield) as a white powder.

{5-[Bis-(2-ethyl-phenyl)-hydroxy-methyl]-2,2-diethyl-[1,3]dioxolan-4-yl}-bis-(2-ethyl-phenyl)-methanol (14): ^1H NMR (DMSO, 140 $^\circ\text{C}$) δ 0.53 (t, $J = 7.3$ Hz, 6H), 0.64 (t, $J = 7.7$ Hz, 6H), 0.80 (t, $J = 7.7$ Hz, 6H), 0.88-0.98 (m, 2H), 1.33-1.21 (m, 2H), 2.26-2.34 (m, 4H), 2.40-2.44 (m, 2H), 2.47-2.55 (m, 2H), 4.80 (s, 2H), 7.11-7.23 (m, 12H), 7.65 (d, $J = 7.7$ Hz, 2H), 7.74 (d, $J = 7.7$ Hz, 2H); ^{13}C NMR (DMSO, 140 $^\circ\text{C}$) δ 6.8, 13.4, 13.4, 24.6, 25.7, 28.2, 78.1, 80.5, 111.2, 123.2, 123.9, 125.5, 126.2, 126.3, 128.4, 128.9, 129.2, 140.3, 143.1, 143.2, 144.2; IR (KBr) 3561, 3241 cm^{-1} .

General procedure for the catalytic one-pot β -cyanohydrin synthesis (Table 2, entry 2): To a mixture of the diol (0.025 mmol) and Ph_3PO (0.025 mmol) in dichloroethane (0.43 mL), $\text{Zr}(\text{O}^i\text{Bu})_4$ (0.025 mmol) was added at 0 $^\circ\text{C}$ and the whole was stirred for 10 min. To the resulting clear solution, BTSP (213 μL , 1 mmol), TMSCN (133 μL , 1 mmol) and **1** (0.5 mmol) were added to start the reaction. The reaction was traced by ^1H NMR. After the specific period at the temperature described in Table 2, the reaction was quenched by addition of sat. NaHCO_3 . The products were extracted with CHCl_3 and the combined organic layers were washed with H_2O and sat. NaCl . Drying over Na_2SO_4 , filtration and evaporation gave the crude silylated β -cyanohydrin. Desilylation was performed with KF in MeOH in the case of **1a-1d**, **1f-1k** and **1m-1o**, with $\text{TsOH} \cdot \text{H}_2\text{O}$ in MeOH in the case of **1l** and with AcOH - THF - H_2O (2:4:1) in the case of **1e**.

(2S*,3R*)-2-Hydroxy-cycloheptanecarbonitrile (2c): ^1H NMR (CDCl_3) δ 1.40-1.59 (m, 4H), 1.62-1.75 (m, 4H), 1.88-1.99 (m, 2H), 2.68 (bt, $J = 3.4, 8.9$ Hz, 1H), 3.06 (bs, 1H), 3.94 (dt, $J = 3.4, 8.2$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 21.7, 25.4, 26.9, 27.3, 35.5, 39.7, 73.1, 122.4; IR (neat) 3424, 2241 cm^{-1} ; MS m/z 140 ($\text{M}^+ + 1$), 139 (M^+), 122 ($\text{M}^+ - \text{OH}$), 111 ($\text{M}^+ - \text{OH} - \text{HCN}$); HRMS ($\text{M}^+ + 1$) Calcd for $\text{C}_8\text{H}_{14}\text{NO}$ 140.1075. Found 140.1073.

(2S*,3R*)-2-Hydroxy-cyclooctanecarbonitrile (2d): ^1H NMR (CDCl_3) δ 1.37-1.81 (m, 10H), 1.86 (ddt, $J = 3.0, 8.5, 15.3$ Hz, 1H), 1.95-2.01 (m, 1H), 2.75 (ddd, $J = 3.0, 7.3, 10.1$ Hz, 1H), 3.01 (bs, 1H), 3.98 (ddd, $J = 2.5, 7.3, 9.8$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 23.8, 25.1, 25.2, 26.0, 26.2, 33.8, 38.2, 72.1, 122.7; IR (neat) 3434, 2241 cm^{-1} ; MS m/z 154 ($\text{M}^+ + 1$), 153 (M^+), 136 ($\text{M}^+ - \text{OH}$); HRMS ($\text{M}^+ + 1$) Calcd for $\text{C}_9\text{H}_{16}\text{NO}$ 154.1232. Found 154.1233.

(2S*,3R*)-4-Cyano-5-hydroxy-cyclohexane-1,2-dicarboxylic acid dimethyl ester (2e): ^1H NMR (CDCl_3) δ 1.65 (ddd, $J = 4.9, 10.7, 14.1$ Hz, 1H), 2.24 (dt, $J = 11.6, 14.4$ Hz, 1H), 2.44 (ddt, $J = 1.2, 4.0, 14.4$ Hz, 1H), 2.47 (dt, $J = 4.0, 14.1$ Hz, 1H), 2.51 (ddd, $J = 4.0, 9.5, 11.6$ Hz, 1H), 2.56 (ddd, $J = 4.0, 4.3, 11.6$ Hz, 1H), 2.78 (s, 1H), 3.31 (ddd, $J = 4.0, 4.6, 4.9$ Hz, 1H), 3.87-3.91 (m, 1H), 3.64 (s x 2, 6H); ^{13}C NMR (CDCl_3) δ 26.0, 34.3, 36.4, 40.4, 41.5, 52.2, 67.2, 120.1, 171.9, 172.7; IR (neat) 3471, 2245, 1731 cm^{-1} ; MS m/z 242 ($\text{M}^+ + 1$), 241 (M^+), 223 ($\text{M}^+ - \text{OH}$), 209 ($\text{M}^+ - \text{MeO}$), 181 ($\text{M}^+ - \text{CO}_2\text{Me}$); HRMS (M^+) Calcd for $\text{C}_{11}\text{H}_{15}\text{NO}_5$ 241.0950. Found 241.0958.

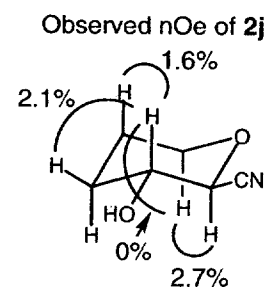
(2S*,3R*)-3-Hydroxy-1,2,3,4-tetrahydro-naphthalene-2-carbonitrile (2f): ^1H NMR (CDCl_3) δ 2.39 (m, 1H), 2.85 (dd, $J = 9.2, 16.5$ Hz, 1H), 2.96 (ddd, $J = 5.5, 9.2, 10.4$ Hz, 1H), 3.15 (dd, $J = 10.4, 16.5$ Hz, 1H), 3.28 (dt, $J = 5.5, 16.5$ Hz, 1H), 4.22-4.27 (m, 1H), 7.09-7.20 (m, 4H); ^{13}C NMR (CDCl_3) δ 31.2, 34.7, 36.7, 67.8, 120.5, 126.7, 127.0, 128.3, 129.4, 132.6; IR (KBr) 3456, 2250 cm^{-1} ; MS m/z 174 ($\text{M}^+ + 1$), 173 (M^+), 155 ($\text{M}^+ - \text{H}_2\text{O}$); HRMS ($\text{M}^+ + 1$) Calcd for $\text{C}_{11}\text{H}_{12}\text{NO}$ 174.0919. Found 174.0919.

(2*S,3*R**)-4-Hydroxy-1-(2,4,6-triisopropyl-benzenesulfonyl)-pyrrolidine-3-carbonitrile (2g):** ^1H NMR (CDCl_3) δ 1.26 (d, $J = 6.7$ Hz, 12H), 1.27 (d, $J = 6.7$ Hz, 6H), 2.86 (bs, 1H), 2.91 (heptet, $J = 6.7$ Hz, 1H), 3.14 (m, 1H), 3.44 (dd, $J = 6.7, 10.7$ Hz, 1H), 3.47 (dd, $J = 3.1, 11.9$ Hz, 1H), 3.56 (dd, $J = 5.2, 11.9$ Hz, 1H), 3.87 (dd, $J = 7.9, 10.7$ Hz, 1H), 4.66 (m, 1H), 7.19 (s, 2H); ^{13}C NMR (CDCl_3) δ 23.5, 24.8, 24.8, 29.5, 34.2, 37.4, 53.3, 74.0, 118.2, 129.9, 151.6, 154.0; IR (KBr) 3434, 2253, 1362, 1149 cm^{-1} ; MS m/z 378 (M^+), 267 (ArSO_2), 202 (Ar); HRMS (M^+) Calcd for $\text{C}_{20}\text{H}_{30}\text{N}_2\text{O}_3\text{S}$ 378.1982. Found 378.1977.

(2*R,3*S**)-2-Butyl-3-hydroxy-heptanenitrile (2h):** ^1H NMR (CDCl_3) δ 0.90 (t, $J = 7.2$ Hz, 3H), 0.91 (t, $J = 7.2$ Hz, 3H), 1.30-1.84 (m, 12H), 2.56 (ddd, $J = 4.0, 5.2, 9.2$ Hz, 1H), 3.62-3.65 (m, 1H); ^{13}C NMR (CDCl_3) δ 13.8, 13.9, 22.2, 22.4, 27.7, 28.7, 29.5, 35.2, 39.3, 71.2, 120.3; IR (neat) 3460, 2242 cm^{-1} ; MS m/z 184 ($\text{M}^+ + 1$), 183 (M^+); HRMS ($\text{M}^+ + 1$) Calcd for $\text{C}_{11}\text{H}_{22}\text{NO}$ ($\text{M}^+ + 1$) 184.1701. Found 184.1702.

(2*R,3*R**)-2-Butyl-3-hydroxy-heptanenitrile (2i):** ^1H NMR (CDCl_3) δ 0.92 (t, $J = 7.3$ Hz, 3H), 0.93 (t, $J = 7.0$ Hz, 3H), 0.39-1.71 (m, 12H), 1.89 (brs, 1H), 2.65 (dt, $J = 5.5, 9.5$ Hz, 1H), 3.72 (ddd, $J = 2.8, 5.8, 9.5$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 13.8, 13.9, 22.2, 22.4, 27.6, 27.6, 29.4, 34.0, 39.4, 71.5, 120.7; IR (neat) 3443, 2243 cm^{-1} ; MS m/z 184 ($\text{M}^+ + 1$), 166 ($\text{M}^+ - \text{OH}$); HRMS ($\text{M}^+ + 1$) Calcd for $\text{C}_{11}\text{H}_{22}\text{NO}$ ($\text{M}^+ + 1$) 184.1701. Found 184.1695.

(2*S,3*R**)-3-Hydroxy-tetrahydro-pyran-2-carbonitrile (2j):** ^1H NMR (CDCl_3) δ 1.59-1.68 (m, 2H), 1.80-1.87 (m, 1H), 2.12-2.18 (m, 1H), 2.71 (bs, 1H), 3.55 (ddd, $J = 3.1, 8.3, 11.6$ Hz, 1H), 3.83-3.86 (m, 1H), 3.92 (ddd, $J = 3.4, 4.9, 11.6$ Hz, 1H), 4.17 (d, $J = 6.7$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 22.2, 29.4, 66.8, 67.2, 70.7, 116.9; IR (neat) 3439, 2254 cm^{-1} ; MS m/z 128 ($\text{M}^+ + 1$), 127 (M^+), 101 ($\text{M}^+ - \text{OH}$); HRMS Calcd for $\text{C}_6\text{H}_9\text{NO}_2$ (M^+) 127.0633. Found 127.0634. The trans stereochemistry was determined by nOe experiments.



(2*S,3*R**)-1-(4'-Nitrobenzenesulfonyl)-3-hydroxy-piperidine-2-carbonitrile**

(2k): ^1H NMR (CDCl_3) δ 1.65-1.70 (m, 1H), 1.85 (ddt, $J = 2.8, 4.3, 13.2$ Hz, 1H), 1.90-1.96 (m, 1H), 2.00 (tq, $J = 4.3, 13.2$ Hz, 1H), 2.85 (dt, $J = 2.8, 13.2$ Hz, 1H), 3.87-3.92 (m, 1H), 4.19-4.21 (m, 1H), 4.93 (bs, 1H), 8.04 (d, $J = 8.9$ Hz, 2H), 8.41 (d, $J = 8.9$ Hz, 2H); ^{13}C NMR (CDCl_3) δ 18.5, 26.4, 38.8, 51.0, 65.8, 113.5, 124.6, 129.0, 142.6, 150.7.

(2*R,3*R**)-1-(4'-Nitrobenzenesulfonyl)-3-hydroxy-piperidine-2-carbonitrile (2k'):** ^1H NMR (CDCl_3) δ 1.56 (dq, $J = 4.0, 13.1$ Hz, 1H), 1.75 (tq, $J = 4.0, 13.1$ Hz, 1H), 1.87-1.91 (m, 1H), 2.09-2.14 (m, 1H), 2.64 (dt, $J = 2.7, 12.5$ Hz, 1H), 3.84-3.87 (m, 1H), 3.94 (dt, $J = 5.5, 13.1$ Hz, 1H), 5.10 (d, $J = 5.5$ Hz, 1H), 8.03 (d, $J = 8.8$ Hz, 2H), 8.44 (d, $J = 8.8$ Hz, 2H); ^{13}C NMR (CDCl_3) δ 23.0, 29.3, 42.3, 52.2, 67.7, 113.1, 124.7, 129.1, 142.0, 143.8.

(1*S,2*R**)-2-Hydroxy-2-methyl-cyclohexanecarbonitrile (2l):** ^1H NMR (CDCl_3) δ 1.39-1.54 (m, 3H), 1.41 (s, 3H), 1.62-1.84 (m, 5H), 1.98-2.04 (m, 1H), 2.64 (dd, $J = 4.0, 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 22.0, 23.0, 25.9, 26.4, 37.6, 40.5, 70.3, 120.8; IR (neat) 3437, 2243 cm^{-1} ; MS m/z 140 ($\text{M}^+ + 1$), 139 (M^+); HRMS Calcd for $\text{C}_8\text{H}_{14}\text{NO}$ ($\text{M}^+ + 1$) 140.1075. Found 140.1076.

(1*S,2*R**)-2-Hydroxy-1-methyl-cyclohexanecarbonitrile (2l'):** ^1H NMR (CDCl_3) δ 1.37 (s, 3H), 1.43-1.81 (m, 11H), 1.87-1.94 (m, 1H), 3.90 (dd, $J = 3.4, 6.4$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 20.5, 21.4, 23.3, 29.7, 32.3, 38.4, 71.3, 124.3; IR (neat) 3453, 2237 cm^{-1} ; MS m/z 140 ($\text{M}^+ + 1$), 139 (M^+), 109 ($\text{M}^+ - \text{CN}$); HRMS Calcd for $\text{C}_8\text{H}_{14}\text{NO}$ ($\text{M}^+ + 1$) 140.1075. Found 140.1075.

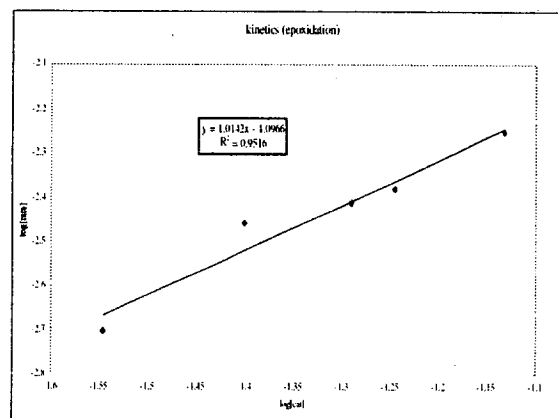
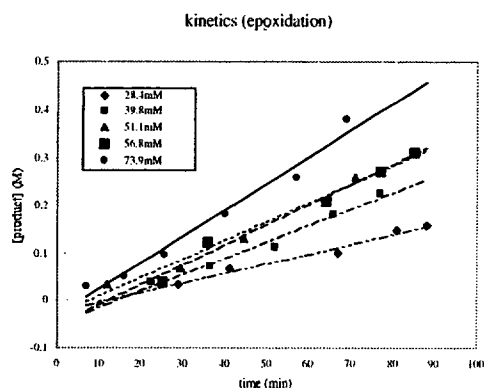
(2*S,3*R**)-3-Hydroxy-2,4-dimethyl-pentanenitrile (2m):** ^1H NMR (CDCl_3) δ 0.98 (d, $J = 6.7$ Hz, 3H), 1.02 (d, $J = 6.7$ Hz, 3H), 1.39 (d, $J = 7.3$ Hz, 3H), 1.79 (bs, 1H), 1.85 (heptet, $J = 6.7$ Hz, 1H), 2.84 (dq, $J = 4.3, 7.3$ Hz, 1H), 3.21-3.26 (m, 1H); ^{13}C NMR (CDCl_3) δ 15.3, 17.5, 19.2, 30.6, 32.2, 77.9, 120.9; IR (neat) 3459, 2245 cm^{-1} ; MS m/z 128 ($\text{M}^+ + 1$), 110 ($\text{M}^+ - \text{OH}$); HRMS Calcd for $\text{C}_7\text{H}_{14}\text{NO}$ ($\text{M}^+ + 1$) 128.1075. Found 128.1076.

3-Hydroxy-octanenitrile (2n): ^1H NMR (CDCl_3) δ 0.88 (t, $J = 6.7$ Hz, 3H), 1.24-1.37 (m, 5H), 1.39-1.48 (m, 1H), 1.52-1.62 (m, 2H), 2.32 (bs, 1H), 2.47 (dd, $J = 6.5, 16.5$ Hz, 1H), 2.55 (dd, $J = 4.9, 16.5$ Hz, 1H), 3.92 (m, 1H); ^{13}C NMR (CDCl_3) δ 13.9, 22.5, 25.0, 26.1, 31.4, 36.5, 67.7, 117.8; IR (neat) 3444, 2252 cm^{-1} ; MS m/z 142 ($\text{M}^+ + 1$), 141 (M^+), 124 ($\text{M}^+ - \text{OH}$); HRMS Calcd for $\text{C}_8\text{H}_{15}\text{NO}$ (M^+) 141.1154. Found 141.1154.

Kinetic studies: The catalyst was prepared according to the general procedure (see page 2). The appropriate amount of dichloroethane was added to get a total volume of 0.48 mL. To the resulting solution, BTSP (213 μL , 1 mmol), TMSCN (133 μL , 1 mmol) and the starting material (cyclohexene (51 μL 0.5 mmol) for the epoxidation step, or cycloheptene oxide (58 μL 0.5 mmol) for the epoxide-opening step) was added to start the reaction. The reaction was monitored by ^1H NMR.

Kinetics study on the epoxidation step

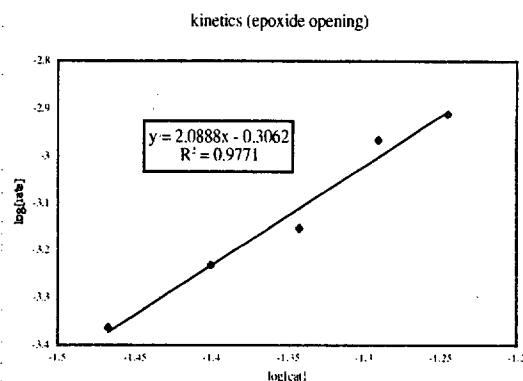
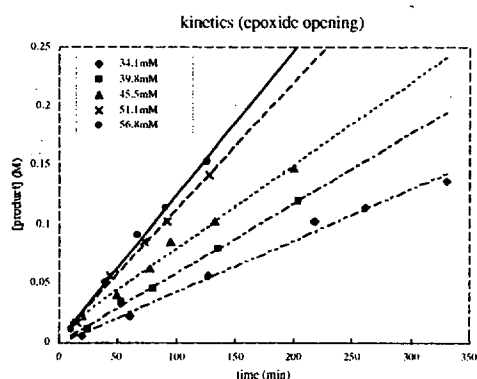
[catalysts](mM)	rate _{obs} (M/min)
28.4	0.0284
39.8	0.0398
51.1	0.0511



56.8	0.0568
73.9	0.0739

Kinetics study on epoxide-opening step

[catalysts](mM)	rate _{obs} ($\times 10^{-3}$ M/min)
34.1	0.435
39.8	0.590
45.5	0.704
51.1	1.076
56.8	1.223



Catalytic enantioselective reaction: To a solution of **14** (0.10 mmol) in CH₂Cl₂ (0.5 mL), Zr(O^tBu)₄ (39 µL, 0.10 mmol) was added under ice bath cooling. The mixture was stirred for 50 min at rt, and then H₂O (1.8 µL, 0.10 mmol) was added. After 45 min, toluene (0.5 mL) was added and the solvent was evaporated under reduced pressure at rt. Co-evaporation was repeated by addition of toluene (0.5 mL) to the resulting residue. After drying the residue for 2 h in vacuo (ca. 3 mmHg), dichloroethane (0.43 mL) was added. Adding BTSP (0.21 mL, 1.0 mmol), TMSCN (133 µL, 1.0 mmol) and **1b** (51 µL, 0.50 mmol) under ice bath cooling, the reaction was performed at 50 °C for 37 h. After workup, desilylation and purification (see general procedure), **2b** was obtained as a colorless oil (67% yield). The absolute configuration of **2b** was determined by the comparison of the optical rotation value.⁴ The ee was determined, after benzylation (BzCl, pyridine and DMAP in CH₂Cl₂), by chiral HPLC analysis (DAICEL CHRALPAK AS, 2-propanol/hexane 10/90, flow 0.5 mL/min, *t*_R 16.7 (major) and 19.3 min (minor)).

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