Supporting Information for:

Cycloruthenated Primary and Secondary Amines as Efficient Catalyst Precursors for Asymmetric Transfer Hydrogenation

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Experimental section:

General procedure for the synthesis of the cycloruthenated compounds:
A suspension of [Ru(η⁶-C₆H₆)Cl₂]₂ (0.200 g, 0.4 mmol), the chiral amine (0.56 mmol), NaOH (0.033 g, 0.83 mmol) and KPF₆ (0.29 g, 1.6 mmol) in CH₃CN (6 mL) was stirred at 20°C under N₂ during 72h. The resulting dark-yellow suspension was filtered over standardized Al₂O₃ (12 x 3 cm) using CH₃CN as eluent. A yellow fraction was collected and concentrated in vacuo to ca. 2 mL. CH₂Cl₂ (2 mL). Diethyl ether (10mL) was added to this solution to give yellow crystals of the complex after standing in the fridge (0°C) for several days.

Typical procedure for the catalytic transfer hydrogenation in Schlenk tubes: The catalyst (10 µmol) was dissolved in 2-propanol (10 mL) under argon, and acetophenone (120 mg, 1 mmol) was added, followed by tBuOK (5.6 mg, 50 µmol). The reaction was periodically monitored by GC. After it was finished, the crude product was filtered over silica gel using Et₂O as eluent. The conversions and ee values were determined by GC using a chiral capillary column (Chiraldex β-PM, 50 m x 0.25 mm).

Typical procedure for the High-Throughput catalytic transfer hydrogenation: The experiment was performed in a Lizzy dispensing robot (Zinnser Analytik), placed in a glove box.
A stock solution of \([\text{Ru}(\eta^6\text{-arene})\text{Cl}_2]_2\) (10.8 mM), NaOH (11.3 mM), and KPF\(_6\) (22 mM) in acetonitrile was prepared under argon. 1mL of this solution was mixed with 1 mL of a 10 mM amine solution in acetonitrile, followed by stirring at 40 °C for 5 h. The solvent was then evacuated by flushing nitrogen at 40 °C for 16 h. The catalyst synthesized in situ was dissolved in 2-propanol (4 mL) under nitrogen and 1 mL of a 560 mM acetophenone solution and 1 mL of a 15 mM \(t\text{BuOK}\) solution in 2-propanol were successively added. The solutions were stirred at room temperature for 4.5 h, then 0.3 mL of glacial acetic acid was added to stop the reaction. An aliquot of 0.1 mL was diluted in 1 mL EtOAc and submitted to GC analysis. The conversions and ee values were determined by GC using a chiral capillary column (Chrompack CP-Sil 5CB, 25 m × 0.25 mm).

**Analytical data for 2**

\(^1\)H NMR (400 MHz, CD\(_3\)CN, 27 °C, TMS): major isomer (54%), \(\delta = 1.44\) (d, \(^3\)\(J_{HH}\) = 6.6 Hz, 3H, CH\(_3\)), 1.96 (s, 3H, CH\(_3\)CN), 3.08 (s, 1H, NH), 3.75 (m, 1H, CH), 5.43 (s, 1H, NH), 5.55 (s, 6H, \(\eta^6\)-C\(_6\)H\(_6\)), 6.82 (d, \(^3\)\(J_{HH}\) = 7.4 Hz, 1H, H\(^4\)), 6.87-7.05 (m, 2H, H\(^2,3\)), 7.75 (dd, \(^3\)\(J_{HH}\) = 7.3 Hz, \(^4\)\(J_{HH}\) = 1.3 Hz, 1H, H\(^1\)) ppm; minor isomer (46%), \(\delta = 1.17\) (d, \(^3\)\(J_{HH}\) = 6.7 Hz, 3H, CH\(_3\)), 1.96 (s, 3H, CH\(_3\)CN), 4.09 (m, 1H, CH), 4.25 (s, 1H, NH), 4.62 (s, 1 H, NH), 5.60 (s, 6 H, \(\eta^6\)-C\(_6\)H\(_6\)), 6.87-7.00 (m, 3 H, H\(^2,3,4\)), 7.83 (d, \(^3\)\(J_{HH}\) = 7.4 Hz, 1H, H\(^1\)) ppm. \(^{13}\)C\{\(^1\)H\} NMR (100 MHz, CD\(_3\)CN, 27 °C, TMS): major isomer, 21.7 (CH\(_3\)), 63.4 (CH\(_2\)CH\(_3\)H\(_3\)), 87.4 (\(\eta^6\)-C\(_6\)H\(_6\)), 122.2 (C\(^4\)), 124.2 (C\(^3\)), 127.4 (C\(^2\)), 139.9 (C\(^1\)), 150.1 (C\(_a\)), 167.3 (C\(_a\)) ppm; minor isomer, 23.1 (CH\(_3\)), 60.1 (CH\(_2\)CH\(_3\)), 87.4 (\(\eta^6\)-C\(_6\)H\(_6\)), 122.2 (C\(^4\)), 124.2 (C\(^3\)), 127.0 (C\(^2\)), 140.1 (C\(^1\)), 153.3 (C\(_a\)), 164.1 (C\(_a\)) ppm. Elemental analysis (%) calcd for C\(_{16}\)H\(_{19}\)F\(_6\)N\(_2\)PRu: C 39.59, H 3.95, N 5.77; found: C 39.10, H 3.96, N 5.76.

**X-ray data for 2**

Crystal structure analysis of 2: C\(_{16}\)H\(_{19}\)N\(_2\)Ru•PF\(_6\), \(M_r = 485.38\), orthorhombic, space group \(P2_12_12_1\), \(a = 9.2385(2)\) Å, \(b = 12.0517(3)\) Å, \(c = 16.4150(5)\) Å, \(V = 1827.64(8)\) Å\(^3\), \(Z = 4\), \(\rho_{\text{calc}} = 1.76\) g cm\(^{-3}\), \(\mu(\text{MoK}\alpha) = 1.005\) mm\(^{-1}\), \(F(000) = 968\), 2.5 < \(\theta\) < 30.04, number of variables = 235, number of data measured = 5241, number of data with \(I > 3\sigma(I) = 3497\), \(R = 0.036\), \(R_W = \ldots\).
0.044, GOF = 1.066, largest peak in final difference: 0.789 e Å⁻³. CCDC-256360 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallography Data Center, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (internat.) + 44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

Analytical data for 3

$^1$H NMR (300 MHz, CD$_3$CN, 20°C, TMS): major isomer (69%), $\delta = 0.92$ (d, $^3$J$_{HH} = 6.9$ Hz, 3H, CH$_3$), $\delta = 1.80$ (d, $^3$J$_{HH} = 6.9$ Hz, 3H, CH$_3$), $\delta = 1.96$ (s, 3H, CH$_3$CN), $\delta = 3.43$ (m, 1H, CHCH$_3$), $\delta = 3.62$ (q, $^3$J$_{HH} = 6.9$ Hz, 1H, CHCH$_3$), $\delta = 5.07$ (d, $^3$J$_{HH} = 11$ Hz, 1H, NH), $\delta = 5.74$ (s, 6H, $\eta^6$-C$_6$H$_6$), $\delta = 6.67$ (dd, $^3$J$_{HH} = 7.4$ Hz, $^4$J$_{HH} = 1.3$ Hz, 1H, H$^4$), $\delta = 6.86$ (td, $^3$J$_{HH} = 7.4$ Hz, $^4$J$_{HH} = 1.2$ Hz, 1H, H$^3$), $\delta = 7.01$ (m, 1H, H$^2$), $\delta = 7.34$-7.54 (m, 5H, Har), $\delta = 7.70$ (dd, $^3$J$_{HH} = 7.5$ Hz, $^4$J$_{HH} = 0.9$ Hz, 1H, H$^1$); minor isomer (29%), $\delta = 1.23$ (d, $^3$J$_{HH} = 6.3$ Hz, 3H, CH$_3$), $\delta = 1.51$ (d, $^3$J$_{HH} = 6.0$ Hz, 3H, CH$_3$), $\delta = 1.96$ (s, 3H, CH$_3$CN), $\delta = 4.34$-4.50 (m, 3H, CHCH$_3$ and NH), $\delta = 5.27$ (s, 6H, $\eta^6$-C$_6$H$_6$), $\delta = 6.92$-7.02 (m, 2H, H$^2$ and H$^3$), $\delta = 7.07$ (dd, $^3$J$_{HH} = 7.1$ Hz, $^4$J$_{HH} = 1.8$ Hz, 1H, H$^4$), $\delta = 7.34$-7.54 (m, 5H, Har), $\delta = 7.62$ (dd, $^3$J$_{HH} = 7.3$ Hz, $^4$J$_{HH} = 1.3$ Hz, 1H, H$^1$) ppm. $^{13}$C{$^{1}$H} NMR (125 MHz, CD$_3$CN, 0 °C, TMS): major isomer, 23.8 (CH$_3$), 25.5 (CH$_3$), 62.7 (CHCH$_3$), 66.1 (CHCH$_3$), 87.7 ($\eta^6$-C$_6$H$_6$), 122.1 (C$^4$), 124.1 (C$^3$), 127.0 (C$^2$), 127.6 (CH$_{ar}$), 128.7 (CH$_{ar}$), 129.7 (CH$_{ar}$), 139.8 (C$^1$), 143.0 (Car), 152.4 (Car), 164.7 (Car) ppm. Elemental analysis (%) calcd for C$_{24}$H$_{27}$F$_6$N$_2$PRu, 2/3 CH$_2$Cl$_2$: C 45.85, H 4.42, N 4.34; found: C 45.55, H 4.48, N 4.13.

Analytical data for 4

$^1$H NMR (300 MHz, CD$_3$CN, 25 °C, TMS): major isomer (97%), $\delta = 1.26$ (d, $^3$J$_{HH} = 6.7$ Hz, 3H, CH$_3$), $\delta = 1.96$ (s, 3H, CH$_3$CN), $\delta = 4.12$ (s, 1H, NH), $\delta = 4.73$ (s, 1H, NH), $\delta = 4.98$ (m, 1H, CHCH$_3$), $\delta = 5.67$ (s, 6H, $\eta^6$-C$_6$H$_6$), $\delta = 7.30$ (ddd, $^3$J$_{HH} = 8.0$ Hz, $^3$J$_{HH} = 6.8$ Hz, $^4$J$_{HH} = 1.1$ Hz, 1H, H$^4$), $\delta = 7.39$ (ddd, $^3$J$_{HH} = 8.0$ Hz, $^3$J$_{HH} = 6.8$ Hz, $^4$J$_{HH} = 1.1$ Hz, 1H, H$^5$), $\delta = 7.54$ (d, $^3$J$_{HH} = 8.2$ Hz, 1H, H$^2$), $\delta = 7.61$ (d, $^3$J$_{HH} = 8.0$ Hz, 1H, H$^6$), $\delta = 7.79$ (d, $^3$J$_{HH} = 8.0$ Hz, 1H, H$^3$), $\delta = 7.99$ (d, $^3$J$_{HH} = 8.2$ Hz, 1H, H$^1$) ppm. $^{13}$C{$^{1}$H} NMR (125 MHz, CD$_3$CN, 0
$^\circ$C, TMS): major isomer, $\delta = 21.5$ (CH$_3$), 59.3 (CHCH$_3$), 87.3 (\$^6$-$\text{C}_6\text{H}_6$), 118.2 (CH$_3$CN), 123.8 
($\text{C}^3$/\$^6$), 124.0 (\$^6$/\$^3$), 126.0 (\$^4$/\$^5$), 126.4 (\$^5$/\$^4$), 132.2 (\text{Car}), 139.2 (\$^1$), 146.7 (\text{Car}), 164.9 (\text{Car}) ppm. Elemental analysis (%) calcd for C$_{20}$H$_{21}$F$_6$N$_2$PRu, 1/4 CH$_3$CN: C 45.12, H 4.02, N 5.78; found: C 45.55, H 4.28, N 5.50.