Electronic Supplementary Information for:

6,6'-Dihydroxy terpyridine: A proton-responsive bifunctional ligand and its application in catalytic transfer hydrogenation of ketones

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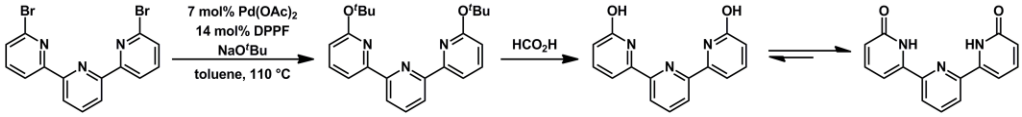
Synthetic Preparations

General Considerations

All liquid ketones used for transfer hydrogenation studies were either distilled under vacuum or vacuum-transferred from an appropriate drying agent and stored over activated molecular sieves in an inert atmosphere glovebox. All solid ketones were thoroughly dried under high vacuum and stored in an inert atmosphere glovebox. All other commercially-available reagents were used as received without further purification. $RuCl_2(PPh_3)_3$ was prepared as previously described.[1] All manipulations were carried out under a purified atmosphere of nitrogen using standard Schlenk techniques or in an MBraun Lab Master 130 or Innovative Technologies Pure Lab^{HE} GP-1 glovebox, unless otherwise stated. NMR spectra were recorded on either a Varian MR400 or a Varian vnmrs 500 spectrometer and are referenced to residual solvent peaks. IR spectra were collected using a Nicolet *i*S10 spectrometer equipped with a diamond attenuated total reflectance (ATR) accessory. GC/MS analyses were performed using a Shimadzu QP-2010 GC/MS. Elemental analysis was performed by Midwest Microlabs, LLC, Indianapolis, IN.



Scheme S1. Synthetic route for 6,6'-dihydroxy terpyridine.

6,6'-di-*tert*-butoxy terpyridine

In a thick-walled Schlenk tube charged with a stirbar, deoxygenated toluene (25 mL) was added to 6,6'-dibromo terpyridine (1.000 g; 2.56 mmol), palladium(II) acetate (0.040 g; 0.18 mmol), 1,1'-bis(diphenylphosphino)ferrocene (0.200 g; 0.36 mmol) and sodium *tert*-butoxide (0.980 g; 10.20 mmol) with stirring. The flask was sealed and stirred at 110 °C for 1 h. The flask was then allowed to cool to room temperature and the resulting mixture was filtered through a small pad of Celite (~4 cm tall x 5 cm diam.) in the open air, and the Celite was rinsed with a minimal amount of toluene. The combined filtrates were concentrated *via* rotary evaporation to give the title compound as a beige solid (0.786 g; 81 %), which was used without further purification. ^{1}H NMR 400 MHz ($CDCl_3$), δ (ppm): 8.29 (d, J = 8 Hz, 2H), 8.18 (d, J = 7.2 Hz, 2H), 7.91 (t, J = 8 Hz, 1H), 7.69 (t, J = 8 Hz, 2H), 6.70 (d, J = 8 Hz, 2H). ^{13}C NMR 125 MHz ($CDCl_3$), δ (ppm): 163.4, 155.7, 153.5, 139.2, 137.7, 120.5, 113.7, 113.5, 79.5, 28.9. IR, neat (cm^{-1}): 2977, 1567, 1429, 1270, 1248, 1171, 792.

6,6'-dihydroxy terpyridine (*formally* 6,6-(pyridine-2,6-diyl)dipyridin-2-one)

6,6'-Di-*tert*-butoxy terpyridine (1.140 g; 3.02 mmol) was dissolved in formic acid (7.0 mL) and stirred for 10 min in the open air. The red solution was then diluted with deionized water (7.0 mL) to produce a thick precipitate. The precipitate was collected on a sintered glass frit and washed with copious amounts of a formic acid/water solution (1:1) until the eluent became colorless. The resulting solid was dried under high vacuum overnight to give the title compound as a pure, white microcrystalline powder (0.640 g; 80 %) with characterization data consistent with that which has been previously reported[2,3]: ^{1}H NMR 400 MHz (DMSO-d_6), δ (ppm): 12.46 (br s, 2H), 8.06 – 8.22 (m, 3H), 7.59 (app. t, J = 7.8 Hz, 2H), 7.09 (d, J = 6.4 Hz, 2H), 6.49 (d, J = 8.8 Hz, 2H). IR, neat (cm^{-1}): 3087, 1655, 1592, 1475, 1226, 1174, 989, 877, 788. ESI-MS: m/z = 266.0 (100%, MH^+).

***trans*-RuCl(terpyOH)(PPh_3)$_2PF_6$ (1)**

In a Schlenk flask charged with a stirbar, deoxygenated methanol (75 mL) was added to the solids 6,6'-dihydroxy terpyridine (0.166 g; 0.626 mmol) and $RuCl_2(PPh_3)_3$ (0.600 g; 0.626 mmol) with stirring. The mixture was heated to a vigorous reflux for 24 h under a nitrogen atmosphere. The mixture was allowed to cool to room temperature and diluted with methanol (75 mL) and then was filtered through a pad of Celite (~4 cm tall x 5 cm diam.) in the open air. The Celite pad was rinsed with methanol until the eluent became colorless. Solid ammonium hexafluorophosphate (1.700 g; 10.43 mmol) was added to the combined filtrates and the solution was placed in a -25 °C freezer overnight, during which time an orange-colored precipitate emerged. The precipitate was collected, washed with copious amounts of diethyl ether and dried under high vacuum to provide the title compound as a mustard yellow powder (0.448 g; 67 %). ^{1}H NMR, 500 MHz (CD_2Cl_2), δ (ppm): 10.16 (s, 2H), 7.63 (t, *J* = 8, 1H), 7.59 (t, *J* = 8, 2H), 7.50 (d, *J* = 8.5, 2H), 7.28 (t, *J* = 7.5, 6H), 7.27 (dd, *J* = 1 and 7.5, 2H), 7.06 (t, *J* = 8, 12H), 6.90 - 6.94 (m, 12H), 6.65 (dd, *J* = 1 and 8.5, 2H). ^{31}P{^{1}H} NMR, 202 MHz (CD_2Cl_2), δ (ppm): 21.70 (s, PPh_3), -144.40 (sep., *J* = 709, PF_6^-). IR, neat (cm^{-1}): 3627, 3100, 1640, 1481, 1434, 1188, 1165, 1090, 833, 788, 744, 695. Anal. Calculated (Found): C, 57.18 (56.95); H, 3.86 (3.87); N, 3.92 (4.04). A crystal suitable for a single crystal X-ray diffraction experiment was grown by vapor diffusion of diethyl ether into a dichloromethane solution of **1** at room temperature.

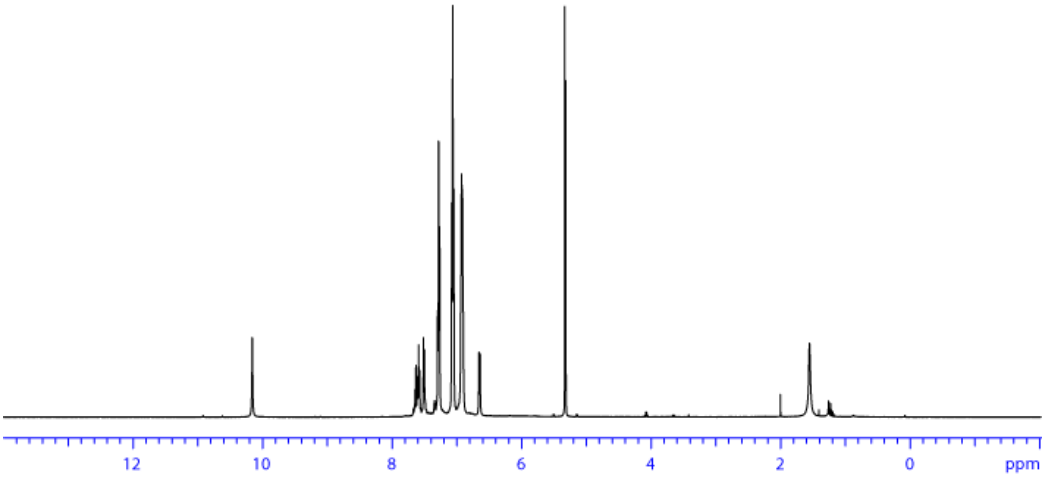


Figure S1. 500 MHz ^{1}H NMR spectrum of **1** in CD_2Cl_2.

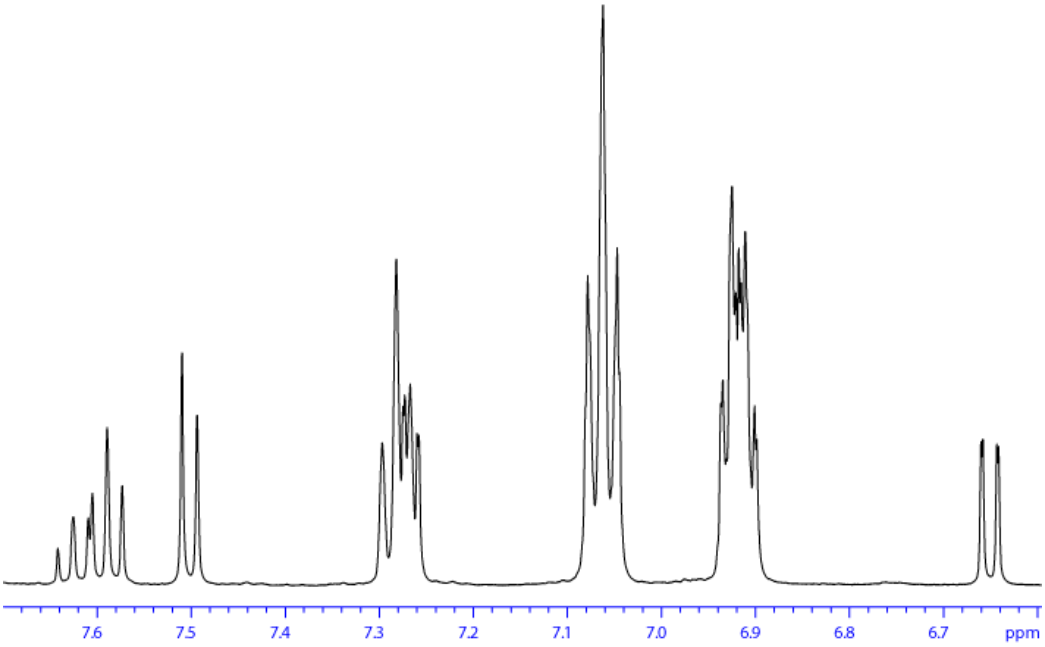


Figure S2. Detail of the aromatic region of the 500 MHz ^{1}H NMR spectrum of **1** in CD_2Cl_2.

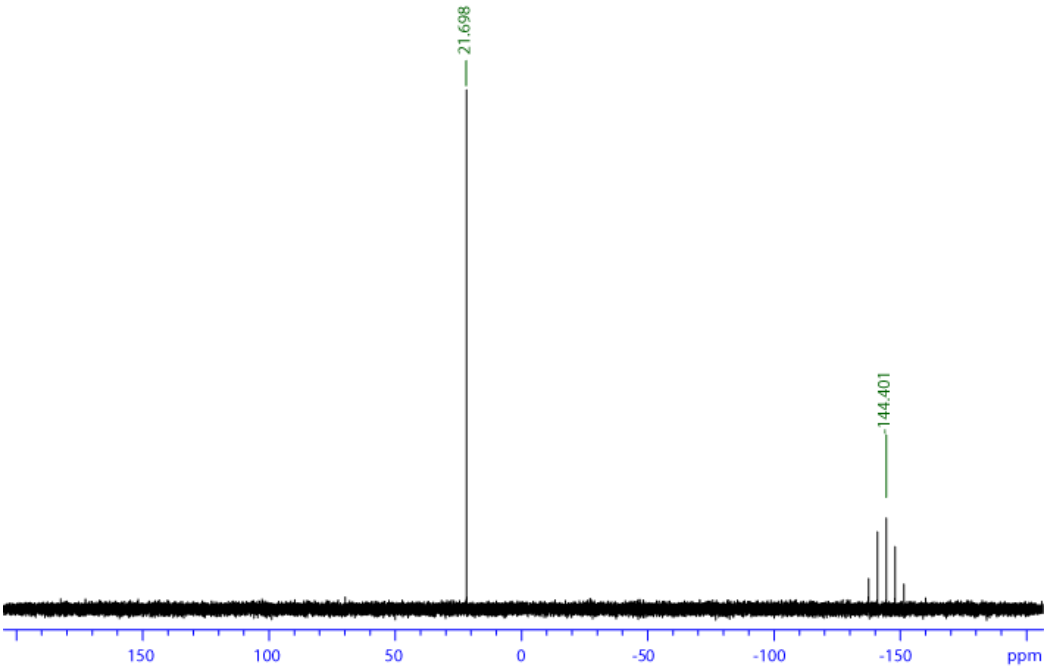


Figure S3. 202 MHz $^{31}P\{^{1}H\}$ NMR spectrum of **1** in CD_2Cl_2.

General procedure for the catalytic transfer hydrogenation of ketones:

These experiments were typically run in NMR tubes as follows:

In a nitrogen-filled glovebox, a catalyst stock solution of **1** and KO^{t}Bu was prepared by adding ^{i}PrOH (10 mL) to **1** (6.5 mg; 0.0061 mmol) and KO^{t}Bu (13.6 mg; 0.12 mmol), which afforded an orange solution. An aliquot of this solution (420 μL; 0.00025 mmol **1** and 0.0050 mmol of KO^{t}Bu) was added to an NMR tube, followed by the ketone substrate (0.05 mmol) and trimethyl(phenyl)silane (5.0 μL; 0.029 mmol) as an internal standard. The solution was diluted with ^{i}PrOH to reach a final volume of 0.500 mL. The tube was sealed inside the glovebox and protected with 3-5 layers of electrical tape. The tube was removed from the glovebox and an initial ^{1}H NMR spectrum was recorded, then the tube was placed in a pre-heated oil bath at 80 °C for 12 h. After this period, a ^{1}H NMR spectrum was recorded and the NMR yield was calculated using the trimethyl(phenyl)silane resonance as an integration standard.

General procedure for determining chemoselectivity:

The general procedure outlined above for the catalytic transfer hydrogenation of ketones was used, except the reactions were performed in a 1 dram vial with stirbar in a nitrogen filled glovebox. Aliquots (20 μL) were taken from the reaction and diluted with dichloromethane (1.0 mL), then analyzed by GC/MS using a Shimadzu QP-2010 GC/MS equipped with a 30 m long DB-5 column with a 0.25 mm inner diameter. The heating scheme used was as follows: 28 °C hold for 15 min, ramp 20 °C/min until 270 °C, and hold 270 °C for 5 min.

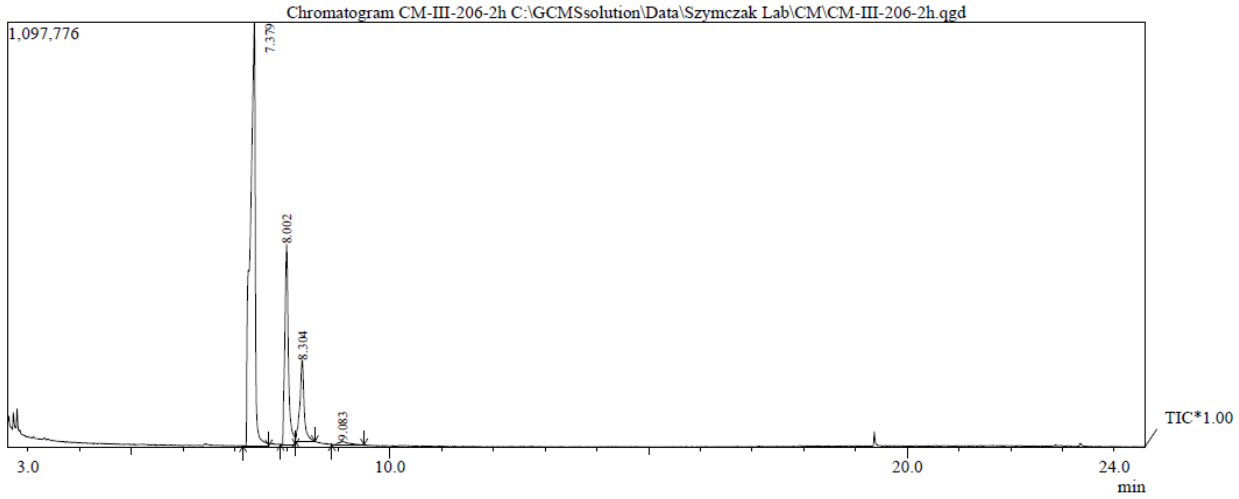


Figure S4. Representative gas chromatogram of products formed during the transfer hydrogenation of 5-hexen-2-one using **1**. Retention times: 7.38 min (5-hexen-2-one), 8.00 min (2-hexanone), 8.30 min (5-hexen-2-ol) and 9.08 min (2-hexanol).

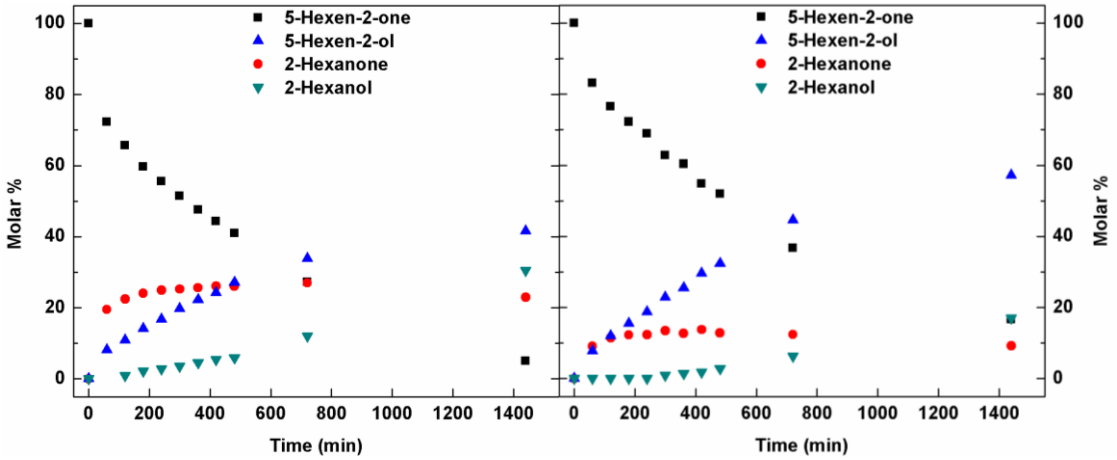


Figure S5. Product distribution during the transfer hydrogenation of 5-hexen-2-one using **1** without (left) and with 1 mol% PPh_3 (right). Conditions: $[acetophenone]_o$ = 0.11 M, $[\mathbf{1}]_o$ = 0.00050 M, $[KO^tBu]_o$ = 0.010 M, ^{i}PrOH, 80 °C.

Hg^0 poisoning experiment:

A related compound, $RuCl_2(PPh_3)_3$, catalyzes transfer hydrogenation *via* formation of Ru-nanoparticles under similar conditions, and in this instance, the addition of Hg^0 significantly affected the reaction profile.[4] To investigate the catalytically-active species derived from **1**/KO^tBu, we performed a similar experiment. The general procedure outlined above for the catalytic transfer hydrogenation of ketones was used with acetophenone as the substrate and two experiments were run in parallel; one serving as the control reaction. These reactions were performed in re-sealable J. Young NMR tubes. The reactions were monitored *via* ^{1}H NMR spectroscopy to ensure reactions had proceeded past the initiation period (*ca*. 30 min). The NMR tubes were introduced into a nitrogen-filled glovebox and a drop of Hg^0 was added to one tube, re-sealed, and vigorously agitated (the control NMR tube was treated identically, without introduction of Hg^0). The tubes were removed from the glovebox, returned to the oil bath, and monitored by ^{1}H NMR spectroscopy for a total period of 5.5 h.

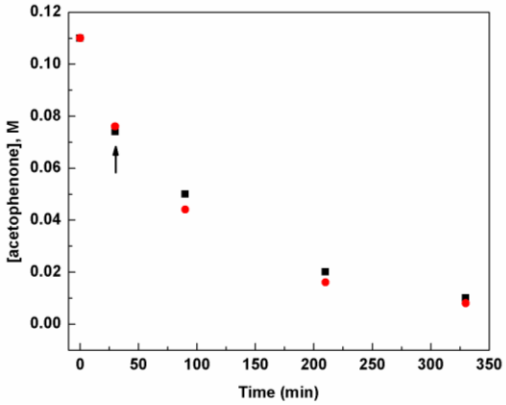


Figure S6. Monitoring the disappearance of acetophenone as a function of time during a Hg^0 poisoning experiment. Hg^0 was added at 30 min (arrow indicates point of addition, ■ indicates experiment w/ Hg^0, ● indicates control w/o Hg^0). Conditions: $[acetophenone]_o$ = 0.11 M, $[\mathbf{1}]_o$ = 0.00050 M, $[KO^tBu]_o$ = 0.010 M, ^{i}PrOH, 80 °C.

Determination of PPh_3 dependence:

The general procedure outlined above for the catalytic transfer hydrogenation of ketones was used with acetophenone as the substrate and varying amounts of a 0.050 M stock solution of PPh_3 in ^{i}PrOH were added (0 μL, 5.0 μL, 10.0 μL and 20.0 μL). The consumption of acetophenone during transfer hydrogenation was monitored *via* ^{1}H NMR spectroscopy using the trimethyl(phenyl)silane resonance as an internal standard. The rate of acetophenone transfer hydrogenation was calculated by plotting the concentration of acetophenone as a function of time between 1 h and 4 h during the reaction; this period was when the rate was constant.[5] These reactions were performed in triplicate, and were used as a basis for error determination by measuring the standard deviation between individual rate calculations (included as error bars in Figure S7).

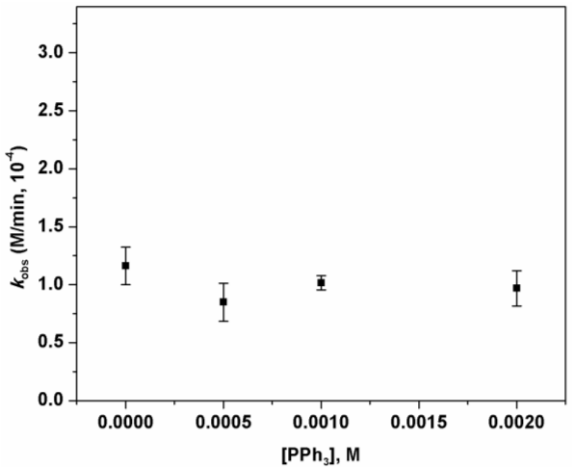


Figure S7. Dependence of PPh_3 on the rate of acetophenone transfer hydrogenation catalyzed by **1**. Conditions: $[acetophenone]_o$ = 0.11 M, $[\mathbf{1}]_o$ = 0.00050 M, $[KO^tBu]_o$ = 0.010 M, ^{i}PrOH, 80 °C.

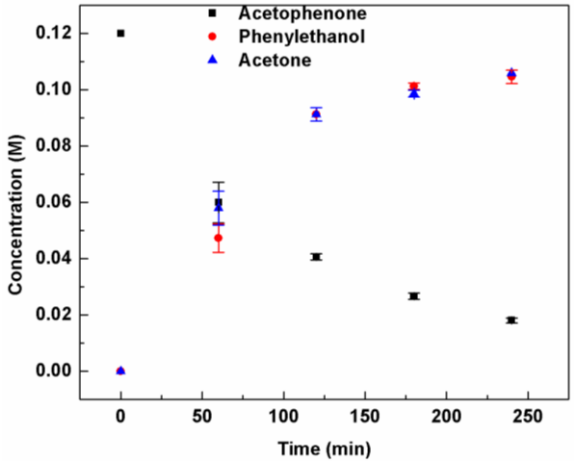


Figure S8. Stoichiometric formation of acetone during transfer hydrogenation of acetophenone catalyzed by **1**. Conditions: $[acetophenone]_o$ = 0.12 M, $[\mathbf{1}]_o$ = 0.00050 M, $[KO^tBu]_o$ = 0.010 M, ^{i}PrOH, 80 °C. Experiment run in triplicate, standard deviation between each measurement included as error bars.

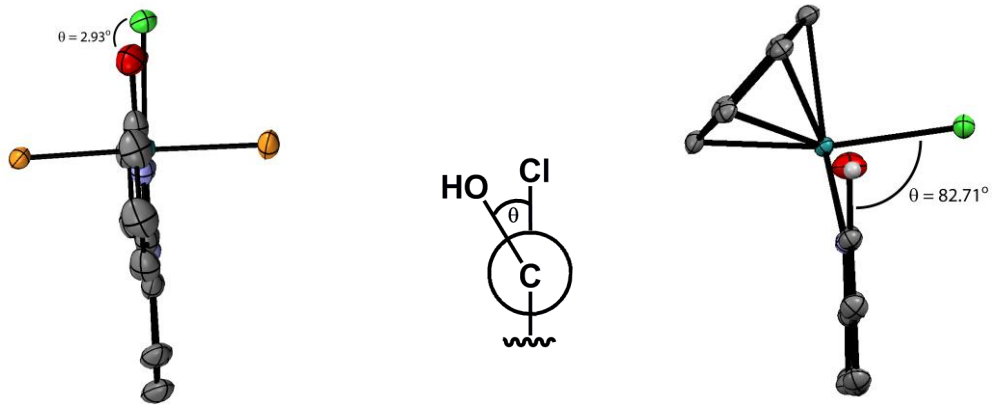


Figure S9. Comparison of the torsion angles between the Ru-Cl and C-O bond vectors in the solid state structures of **1** (left) and [(η^6-*p*-cymene)Ru(dhbp)Cl]$^+$ (right).[6] Extraneous carbon atoms (on PPh_3 or arene ligands) removed for clarity.

References

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