Supporting Information

Novel Sulfinyl Imine Ligands for Asymmetric Catalysis

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General Methods. Unless otherwise noted, materials were obtained from commercial suppliers and used without further purification. All reactions were performed under nitrogen atmosphere in flame-dried glassware. Reaction solvents were distilled under nitrogen immediately before use: tetrahydrofuran (THF) and diethylether (Et_2O) from Na/benzophenone ketyl, methylene chloride (CH_2Cl_2), benzene (C_6H_6), *N*,*N*-diisopropylethylamine (Hunig's Base), and acetonitrile (CH_3CN) from CaH_2. 1, 3-diphenylpropenyl acetate[1] and di-*o*-tolylchlorophosphine[2] were prepared by known methods. Flash chromatography was carried out using Merck 60 230-240 mesh silica gel. Thin layer chromatography analysis was performed on Merck 60 F_{254} 250-μm silica gel plates. Infrared spectra were recorded using NaCl plates or reflectance IR. NMR chemical shifts were measured in $CDCl_3$ and are reported in ppm. ^1H NMR shifts are referenced to residual protonated solvent. ^{31}P NMR shifts are referenced to 85% H_3PO_4 as an external standard. Coupling constants are reported in Hz. Elemental analyses were performed by the University of California at Berkeley Micro-Mass Facility. X-ray analysis was performed by the University of California at Berkeley CHEXray facility.

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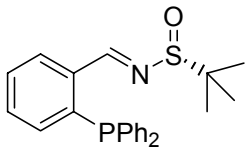
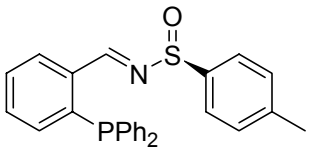
[1] Aramine, A.; Kahn, M,; Mitra, A.J. *J. Org. Chem.* **1978**, *43*, 2923. Lin, M-H.; Rajanbabu, T.V. *Org. Lett.* **2000**, *2*, 997.

[2] Clark, P.; Mulraney B. *J. Organomet. Chem.* **1981**, *217*, 51.

General Procedure for the Synthesis of Ligands. To a flask containing a solution of the sulfinamide and the aldehyde or ketone was added $Ti(OEt)_4$ (containing 5-15% isopropanol, ~2 equiv), and the reaction mixture was heated. Upon reaction completion, the reaction mixture was allowed to cool to room temperature, diluted with EtOAc, and poured into brine with rapid stirring. The resulting suspension was filtered through a plug of Celite and the filter cake washed with EtOAc. The filtrate was transferred to a separatory funnel, and the organic layer was washed with an equal volume of brine. The organic phase was dried ($MgSO_4$), filtered, concentrated, and purified by flash chromatography.

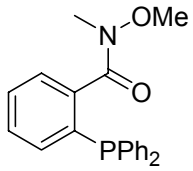


(*R*)-(-)**-*N*-(2-(Diphenylphosphino)-benzylidene)-*tert*-butanesulfinamide (3).** The general procedure was followed at 50 °C with *tert*-butanesulfinamide (97.0 mg, 0.800 mmol), 2-(diphenylphosphino)-benzaldehyde (232 mg, 0.800 mmol), and $Ti(OEt)_4$ (0.37 mL, ~1.6 mmol) in 3.2 mL of THF. Chromatography (85/15 hexanes/EtOAc) delivered 240 mg (77%) of **3** as a yellow oil, $[\alpha]_D$ = -54.2° (*c* 1.0, $CHCl_3$). IR: 1087 cm^{-1}. ^1H NMR (400 MHz): δ 1.08 (s, 9H), 6.94-6.98 (m, 1H), 7.23-7.48 (m, 12H), 7.98-8.02 (m, 1H), 9.11 (d, 1H, *J* = 4.8). ^{31}P NMR (160 MHz): δ -11.7. MS (FAB): *m/z* 394 (MH^+). Anal. Calcd. for $C_{23}H_{24}NOPS$: C, 70.21; H, 6.15; N, 3.56. Found: C, 70.03; H, 6.27; N, 3.36.

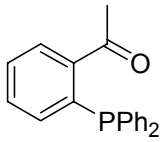


(*S*)-(+)**-*N*-(2-(Diphenylphosphino)-benzylidene)-*p*-toluenesulfinamide (4).** The general procedure was followed at 50 °C with *p*-toluenesulfinamide (50

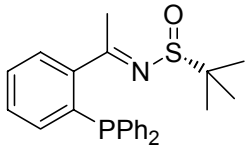
mg, 0.32 mmol), 2-(diphenylphosphino)-benzaldehyde (94 mg, 0.32 mmol), and $Ti(OEt)_4$ (0.15 mL, ~0.64 mmol) in 1.3 mL of THF. Chromatography (80/20 hexanes/EtOAc) delivered 73 mg (53%) of **4** as a light yellow solid, $[\alpha]_D$ = +123.8° (*c* 0.5, $CHCl_3$). mp: 115-117 °C. IR: 1094 cm^{-1}. ^1H NMR (400 MHz): δ 2.37 (s, 3H), 6.95 (m, 1H), 7.16-7.34 (m, 16H), 7.96 (m, 1H), 9.38 (d, 1H, *J* = 4.8). ^{31}P NMR (160 MHz): δ -12.7. MS (FAB): *m/z* 428 (MH^+). Anal. Calcd. for $C_{26}H_{22}NOPS$: C, 73.05; H, 5.19; N, 3.28. Found: C, 73.32; H, 5.13; N, 3.35.



***N*-Methoxy-*N*-methyl-(2-diphenylphosphino)-benzamide (5).** A solution of 2-(diphenylphosphino)-benzoic acid (5.0 g, 16 mmol), 1-hydroxybenzotriazole hydrate (2.4 g, 18 mmol), Hunig's base (2.8 mL, 16 mmol), and *O*, *N*-dimethylhydroxylamine hydrochloride (1.6 g, 16 mmol) was prepared in 86 mL of CH_2Cl_2 and stirred for 10 min until the reaction mixture became homogeneous. To the solution was added 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (3.4 g, 18 mmol), and stirring was continued at room temperature for 3 h. The reaction mixture was poured into an equal volume of water, and the layers were separated. The organic phase was washed with water (100 mL) and brine (100 mL), dried ($MgSO_4$), and concentrated. The crude yellow oil was purified by flash chromatography (75/25 hexanes/EtOAc, then 60/40 hexanes/EtOAc) to give **5** as a colorless oil that crystallized upon standing (4.0 g, 70%), mp 86-88 °C. IR: 1644 cm^{-1}. ^1H NMR (300 MHz): δ 3.21 (br s, 3H), 3.50 (br s, 3H), 7.16-7.17 (m, 1H), 7.30-7.40 (m, 13H). ^{31}P (160 MHz): δ -11.2. MS (FAB): *m/z* 350 (MH^+). Anal. Calcd. for $C_{21}H_{20}NO_2P$: C, 72.20; H, 5.77; N, 4.01. Found: C, 72.22; H, 5.77; N, 4.16.

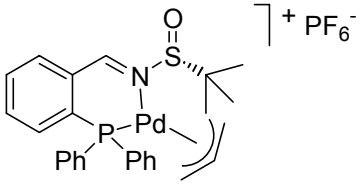


2-(Diphenylphosphino)-acetophenone (6). *N*-Methoxy-*N*-methyl-(2-diphenylphosphino)-benzamide **5** (2.0 g, 5.7 mmol) was dissolved in 57 mL of THF and cooled to 0 °C. Methylmagnesium bromide (3.0 M in Et_2O, 4.0 mL, 12 mmol) was added to the flask dropwise over 10 min. The colorless solution became progressively darker pink while stirring over the course of 2 h at 0 °C. The reaction mixture was allowed to warm to room temperature and poured into an equal volume of 5% HCl in MeOH, at which time the solution became bright yellow. The solution was diluted with CH_2Cl_2 (25 mL) and poured into an equal volume of brine. The resulting suspension was filtered through a pad of Celite and the filter cake was washed with CH_2Cl_2. The filtrate was transferred to a separatory funnel and washed with brine (100 mL). The organic phase was dried ($MgSO_4$), concentrated, and purified by flash chromatography (75/25 hexanes/EtOAc) to give **6** as yellow solid (1.2 g, 66%), mp 142-143 °C. IR: 1667 cm^{-1}. ^1H NMR (500 MHz): δ 2.59 (s, 3H), 7.02-7.04 (m, 1H), 7.28-7.46 (m, 12H), 7.94-7.96 (m, 1H). ^{31}P (160 MHz): δ -2.1. MS (EI): *m/z* 304 (M^+). Anal. Calcd. for $C_{20}H_{17}OP$: C, 78.93; H, 5.63. Found: C, 78.62; H, 5.74.

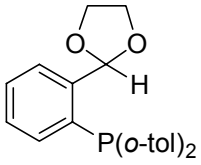


(*R*)-(+)-*N*-(2-(Diphenylphosphino)-phenylethylidene)-*tert*-butanesulfinamide (7). The general procedure was followed at 75 °C with *tert*-butanesulfinamide (199 mg, 1.64 mmol), 2-(diphenylphosphino)-acetophenone **6** (500 mg, 1.64 mmol), $Ti(OEt)_4$ (0.800 mL, ~3.30 mmol) in 8.2 mL of toluene. Chromatography (80/20 hexanes/EtOAc) provided **7** as a white solid (220 mg,

33%), $[\alpha]_D$ = -161.0° (*c* 0.6, $CHCl_3$). mp: 99-102 °C, IR: 1068 cm^{-1}, ^1H NMR (500 MHz, 60 °C): δ 1.06 (s, 9H), 2.73 (s, 3H), 7.04-7.06 (m, 1H), 7.23-7.41 (m, 13H). ^{31}P (160 MHz): δ -11.9. MS (FAB): *m/z* 408 (MH^+). Anal. Calcd. for $C_{24}H_{26}NOPS$: C, 70.74; H, 6.43; N, 3.44; S, 7.87. Found: C, 70.57; H, 6.15; N, 3.30; S, 7.86.

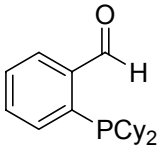


(η^3-Allyl)[(*R*)-(-)-*N*-(2-(diphenylphosphino)-benzylidene)-*tert*-butanesulfinamide] palladium (II) hexafluorophosphate (8). A solution of **3** (45 mg, 0.12 mmol) and [Pd(allyl)Cl_2] (20 mg, 0.06 mmol) in 2.9 mL of CH_2Cl_2 was prepared and degassed (three freeze-pump-thaw cycles). After stirring this solution at room temperature for 1 h, a solution of $AgPF_6$ (30 mg, 0.12 mmol) in 2.4 mL of THF was added to the reaction mixture. The resulting heterogeneous mixture was stirred for 15 min and then filtered through a pad of Celite. The filter cake was washed with CH_2Cl_2 and the filtrate was concentrated to give 78 mg of a yellow solid (99% crude yield). MS (FAB): 540 (MH^+- PF_6). Single crystals suitable for X-ray diffraction were obtained by vapor diffusion of Et_2O into a solution of **8** in $CHCl_3$, which produced **8** as white needles.



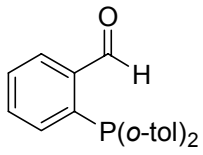
(2-[1,3] Dioxolan-2-yl-phenyl)-di-*o*-tolylphosphine (10). Magnesium (159 mg, 6.55 mmol) was flame-dried under vacuum in a round bottom flask equipped with a reflux condenser and an addition funnel. THF (2.5 mL) was

added, and the mixture was heated to reflux. A single chip of iodine was added, followed by dropwise addition of a solution of 2-(2-bromophenyl)-[1,3]dioxolane (1.00 g, 4.37 mmol) in THF (4.4 mL). After addition was complete, the reaction mixture was stirred at reflux for 1 h. The Grignard reagent mixture was allowed to cool to rt, and added via cannula to a solution of di-*o*-tolylchlorophosphine (1.09 g, 4.37 mmol) in THF (4.4 mL) at 0 °C. The reaction mixture was allowed to warm to rt, and heated to 50 °C for 12 h. After cooling to rt, a few drops of 1M Na_2SO_4 was added, and the reaction mixture was diluted with ether (25 mL). The organic layer was washed with an equal volume of H_2O, followed by an equal volume of brine, dried (Na_2SO_4), concentrated, and purified by flash chromatography (95/5 hexanes/EtOAc) to give **10** as a colorless solid (949 mg, 60%), mp 142-143 °C. IR: 2879 cm^{-1}. ^1H NMR (300 MHz): δ 2.36 (s, 6H), 3.95-3.98 (m, 2H), 4.09-4.12 (m, 2H), 6.46 (d, 1H, J_{HP} = 5.4), 6.72-6.76 (m, 2H), 6.85-6.92 (m, 1H), 7.06-7.09 (m, 2H), 7.22-7.29 (m, 5H), 7.42-7.43 (m, 1H), 7.70-7.72 (m, 1H). ^{31}P NMR (160 MHz): δ -31.3. MS (ESI): *m/z* 363 (MH^+). Anal. Calcd. for $C_{23}H_{23}O_2P$: C, 76.23; H, 6.40. Found: C, 75.95; H, 6.28.



2-(Dicyclohexylphosphino)-benzaldehyde (11). A solution of 2-(2-bromophenyl)-[1,3]dioxolane (300 mg, 1.31 mmol) in Et_2O (7.7 mL) was prepared and cooled to –78 °C. *t*-BuLi (1.1M in pentane, 2.40 mL, 2.62 mmol) was added, and the solution was stirred at –78 °C for 1 h. Dicyclohexylchlorophosphine (0.350 mL, 1.57 mmol) was added, and the reaction mixture was stirred at rt for 12 h. The reaction mixture was poured into deoxygenated H_2O (6 mL) and the layers were separated. The aqueous layer was extracted with Et_2O, and the combined organic layers were dried (Na_2SO_4) and concentrated to give **9** as a

crude yellow oil.[3] Compound **9** was immediately dissolved in deoxygenated acetone (10 mL) and added to a round bottom flask equipped with a reflux condenser. Deoxygenated H_2O (0.500 mL) and a catalytic amount of *p*-toluenesulfonic acid were added, and the reaction mixture was heated to reflux for 24 h. Deoxygenated H_2O (10 mL) and Et_2O (10 mL) were added and the layers were separated. The organic portion was dried (Na_2SO_4), concentrated, and purified by flash chromatography through a short silica gel column with N_2 pressure (100% CH_2Cl_2) to give **11** as a colorless oil (142 mg, 36%). IR: 1687 cm^{-1}. ^1H NMR (400 MHz): δ 0.97-1.34 (m, 11H), 1.56-2.03 (m, 11H), 7.44-7.47 (m, 1H), 7.54-7.57 (m, 2H), 7.97-7.99 (m, 1H), 11.03 (d, 1H, J_{HP} = 8.0). ^{31}P NMR (160 MHz): δ -20.1. Exact mass calcd for $C_{19}H_{28}OP$ requires *m/z* 303.1878, found *m/z* 303.1871 (MH^+, FAB).



2-(Di-*o*-tolylphosphino)-benzaldehyde (12). (2-[1,3] Dioxolan-2-yl-phenyl)-di-*o*-tolylphosphine **10** (750 mg, 2.07 mmol) was dissolved in acetone (30 mL). H_2O (1.00 mL) and a catalytic amount of *p*-toluenesulfonic acid were added and the reaction mixture was heated to reflux for 15 h. H_2O (30 mL) and Et_2O (30 mL) were added and the layers were separated. The organic portion was dried (Na_2SO_4), concentrated, and purified by flash chromatography (95/5 hexanes/EtOAc) to give **12** as a yellow oil that crystallized upon standing (600 mg, 91%), mp 114-117 °C. IR: 1690 cm^{-1}. ^1H NMR (300 MHz): δ 2.43 (s, 6H), 6.69-6.73 (m, 2H), 6.90-6.94 (m, 1H), 7.07-7.10 (m, 2H), 7.25-7.29 (m, 4H), 7.46-7.51 (m, 2H), 8.01-8.02 (m, 1H), 10.59 (d, 1H, J_{HP} = 6.0). ^{31}P NMR (160 MHz): δ -28.8. MS (ESI): *m/z* 319 (MH^+). Anal. Calcd. for $C_{21}H_{19}OP$: C, 79.23; H, 6.02. Found: C, 79.01; H, 5.93.

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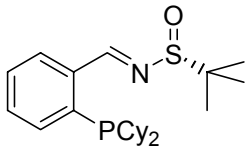
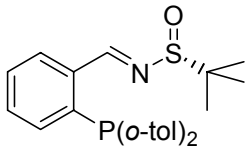
[3] Bei, X.; Turner, H.; Weinberg, H.; Guram, A.; Peterson, J. *J. Org. Chem.* **1999**, *64*, 6797.



(*R*)-(-)**-*N*-(2-(Dicyclohexylphosphino)-benzylidene)-*tert*-butanesulfinamide (13).** The general procedure was followed with *tert*-butanesulfinamide (12.0 mg, 0.099 mmol), 2-(dicyclohexylphosphino) benzaldehyde **11** (30.0 mg, 0.099 mmol), and $Ti(OEt)_4$ (0.48 mL, ~ 1.99 mmol) in 0.50 mL of THF at rt. Flash chromatography (90/10 hexanes/EtOAc) delivered **13** as a white solid (25.0 mg, 62%), $[\alpha]_D$ = -169.0° (*c* 1.0, $CHCl_3$), mp 141-143 °C. IR: 1087 cm^{-1}. ^1H NMR (300 MHz): δ 0.92-1.30 (m, 11H), 1.26 (s, 9H), 1.42-1.99 (m, 11H), 7.39-7.57 (m, 3H), 8.09-8.13 (m, 1H), 9.69 (d, 1H, J_{HP} = 7.5). ^{31}P NMR (160 MHz): δ -17.6. MS (ESI): *m/z* 406 (MH^+). Anal Calcd. for $C_{23}H_{36}NOPS$: C, 68.11; H, 8.95; N, 3.45. Found: C, 68.04; H, 9.10; N, 3.12.



(*R*)-(-)**-*N*-(2-(Di-*o*-tolylphosphino)-benzylidene)-*tert*-butanesulfinamide (14).** The general procedure was followed with *tert*-butanesulfinamide (38.0 mg, 0.314 mmol), 2-(di-*o*-tolylphosphino)benzaldehyde **12** (100 mg, 0.314 mmol), and $Ti(OEt)_4$ (0.150 mL, ~ 0.628 mmol) in 1.3 mL of THF at 50 °C. Flash chromatography (85/15 hexanes/EtOAc) delivered **14** as a yellow oil which can be solidified by repeated concentrations from Et_2O (116 mg, 88%, $[\alpha]_D$ = -57.5° (*c* 1.0, $CHCl_3$). IR: 1080 cm^{-1}. ^1H NMR (500 MHz): δ 1.05 (s, 9H), 2.39 (d, 3H, J_{HP} = 1.5), 2.40 (d, 3H, J_{HP} = 1.5), 6.65-6.72 (m, 2H), 6.92-6.95 (m, 1H), 7.03-7.06 (m, 2H), 7.21-7.28 (m, 4H), 7.33-7.38 (m, 1H), 7.43-7.48 (m, 1H), 8.02 (m, 1H), 9.21 (d, 1H, J_{HP} = 5.5). ^{31}P NMR (160MHz): δ -29.0. MS (ESI): *m/z* 422 (MH^+).

Anal. Calcd. for $C_{25}H_{28}NOPS$: C, 71.23; H, 6.70; N, 3.32. Found: C, 70.86; H, 6.40; N, 3.13.

General Procedure for Allylic Alkylations of 1,3-diphenylpropenyl acetate. To a Schlenk flask containing ligand was added the palladium reagent dissolved in the reaction solvent. The flask was immediately degassed (three freeze-pump-thaw cycles), and the solution was stirred at room temperature for 1 h. The flask was opened under N_2, and the solution was treated sequentially with 1,3-diphenylpropenyl acetate (1 equiv) in a minimal amount of reaction solvent, dimethyl malonate (3 equiv), *N*,*O*-bis(trimethylsilyl)acetamide (3 equiv), and potassium acetate (0.05 equiv). The flask was immediately degassed (three freeze-pump-thaw cycles) and the reaction mixture was stirred at room temperature. Upon completion the reaction mixture was diluted with EtOAc and washed with saturated NH_4Cl. The organic portion was dried (Na_2SO_4), filtered through a plug of silica gel, and concentrated. The %ee was determined by HPLC analysis (Daicel Chiralpak AD, flow rate 1.0 mL/min, 95% hexanes, 5% *i*-PrOH, t_R = 13.9, 19.4 min). The absolute stereochemistry was determined by comparison of the HPLC retention time to that of the product prepared using a known ligand prepared by literature procedures.[4] The isolated yield was determined after flash chromatography (75/25 hexanes/EtOAc) provided the product as a colorless oil.[1]

[4] von Matt, P.; Pfaltz, A. *Agnew. Chem. Int. Ed. Engl.* **1993**, *32*(4), 566.