Squaramide-Catalyzed Enantioselective Friedel-Crafts Reaction of Indoles with Imines

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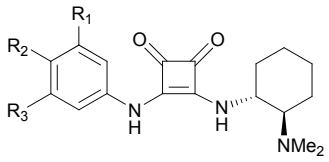
Supplementary Information

Table of Contents

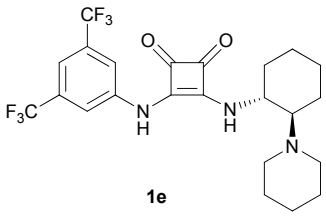
General Methods

^{1}H and ^{13}C-NMR spectra were recorded with tetramethylsilane as the internal standard on a Bruker p[p[DPX 300 model Spectrometer in $CDCl_3$-d^6 and Chemical shifts were reported in ppm (δ). ESI-MS spectra were recorded on a Mariner System 5304 Mass spectrometer. Elemental analyses were performed on a CHN-O-Rapid instrument. TLC was performed on the glass-backed silica gel sheets (silica gel HG/T2354-92 GF254) and visualized in UV light (254 nm). Column chromatography was performed using silica gel (200-300 mesh) eluting with ethyl acetate and petroleum ether. The enantiomeric excess value determination was carried out using chiral HPLC with Daicel Chiralcel OD-H column. All solvents were purified and dried according to standard methods prior to use.

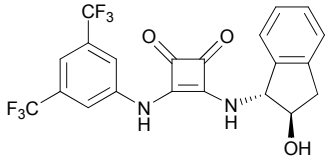
Synthesis of Catalyst



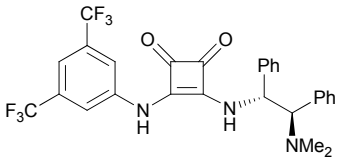
1a: R_1=CF_3, R_2=H, R_3=CF_3;
1b: R_1=F, R_2=H, R_3=F;
1c: R_1=F, R_2=F, R_3=F;
1d: R_1=Cl, R_2=H, R_3=Cl.



1e

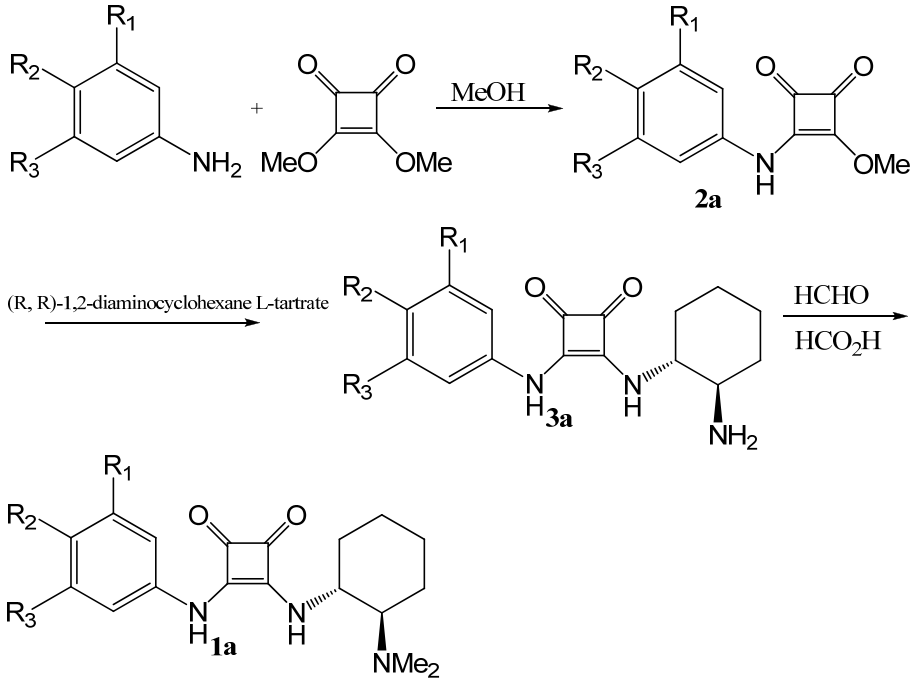


1f



1g

Catalyst 1a[1], **1b**[1], **1c**[1], **1d**[1] **1f**[1] were prepared according to the reported procedures.

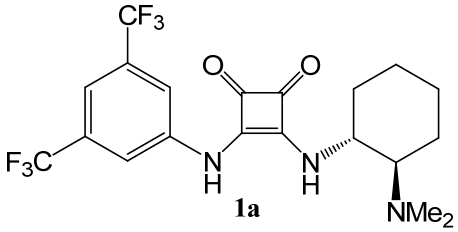


To a solution of 3,4-dimethoxy-3-cyclobutane-1,2-dione (2.00g, 14.1mmol) in MeOH (20ml) was added 3,5-bis(trifluoromethyl)aniline (2.40ml, 15.5mmol, 1.1equiv) at rt. The mixture was stirred at rt for 3 days. The reaction mixture was filtrate and washed with MeOH. Obtained yellow solid was dried *in vacuo* to give desired product **2a** (4.59, 13.5mmol, 96%).

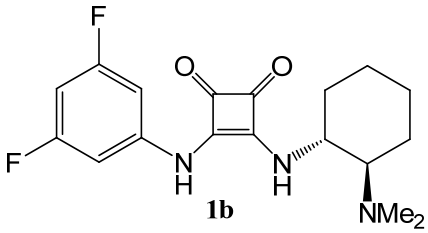
To a suspension of (R, R)-1,2-diaminocyclohexane L-tartrate (857mg, 3.24mmol,1.1equiv) in MeOH (10ml) was added K_2CO_3 (896mg, 6.94mmol, 2.2equiv) at rt. The reaction mixture was stirred at rt for 4h. The reaction mixture was diluted with $CHCl_3$ (100ml) and filtrated through a pad of celite. The filtrate and washing were combined and concentrated in vacuo to give crude product **3a**.

To a solution of crude **3a** in MeOH (10ml) was added 37%aqueous HCHO (5ml, 67mmol, 23equiv) and HCO_2H (5ml, 133mmol, 45equiv) at rt. The reation mixture was stirred under reflux for 12h. the reaction mixture was basified by 6mol/L aqueous NaOH to pH 12 and then extracted with CH_2Cl_2. The combined organic layer was dried over Mg_2SO_4 and then concentrated. Obtained residu was purified by recrytallization from *i*-PrOH and H_2O to give desired product **1a**.

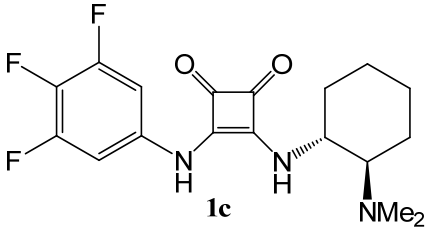
Synthesis of catalysts **1b**, **1c**, **1d, 1f** followed the above method.



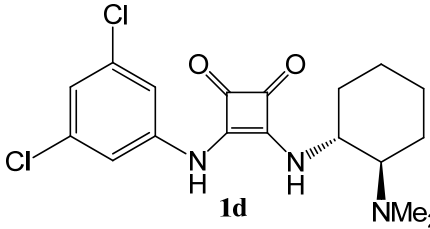
White solid; ^{1}H NMR(300MHz,DMSO-d_6,303K) δ 10.25（s,1H）, 8.04 (s, 2H), 7.77 (s, 1H), 7.63(s, 1H), 3.83 (s, 1H), 3.82-2.36 (m, 1H), 2.13 (s, 6H), 2.09 (m, 1H), 1.72 (m, 3H), 1.31 (m, 4H). ^{13}C NMR (300 MHz, $CDCl_3$) δ 185.7, 180.1, 169.5, 162.3, 141.4, 131.4 (q, $J_{F\text{-}C}$=32.7Hz), 122.8 (q, $J_{F\text{-}C}$=271.1Hz), 118.2, 114.7, 66.3, 54.9, 40.2, 34.6, 24.5, 21.4. HRMS (ESI): calcd for $C_{20}H_{22}F_6N_3O_2$ $[M+H]^+$, 450.1616; found, 450.1605.



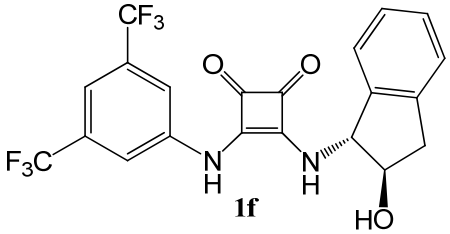
1b Gray solid; ^{1}H NMR(300MHz,DMSO-d6,303K) δ 10.0（s, 1H）, 7.83 (s, 1H), 7.19 (d, *J* = 7.68Hz, 2H), 6.84 (t, *J* = 9.33Hz, 1H), 3.87 (s, 1H), 2.21 （s, 6H）, 2.06-1.66 (m, 4H), 1.33-1.20 (m, 5H). ^{13}C NMR (300 MHz, $CDCl_3$) δ 184.5, 179.9, 169.2, 163.1, 162.6, 142.0, 106.6, 97.4, 66.3, 54.9, 40.1, 34.6, 24.5, 21.4. HRMS (ESI): calcd for $C_{18}H_{22}F_2N_3O_2$ $[M+H]^+$, 350.1680; found, 350.1675.



1c Gray solid; ^{1}H NMR(300MHz,DMSO-d6,303K) δ 9.82（s, 1H）, 7.73 (s, 1H), 7.36(s, 1H), 7.26 (s, 1H), 3.86 (s, 1H), 2.19 （s, 6H）, 1.76-1.66 (m, 4H), 1.37-1.20 (m, 5H). ^{13}C NMR (300 MHz, $CDCl_3$) δ 184.4, 179.9, 174.5, 169.4, 162.5, 142.0, 106.6, 97.4, 66.3, 54.9, 40.2, 34.7, 24.5, 21.4. HRMS (ESI): calcd for $C_{18}H_{21}F_3N_3O_2$ $[M+H]^+$, 368.1586; found, 368.1580.

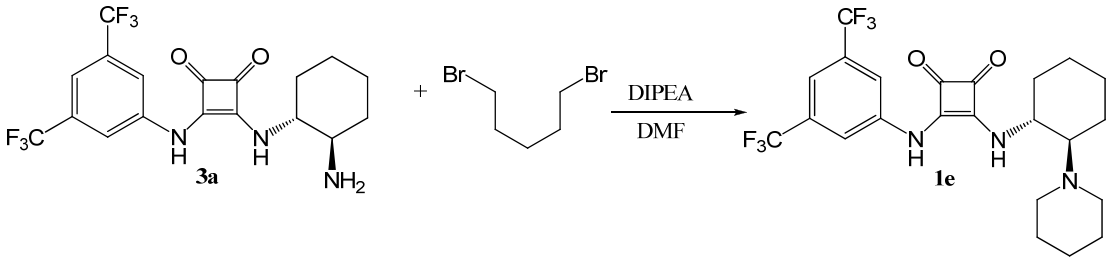


1d Pale brown solid; ^{1}H NMR(300MHz,DMSO-d6,303K) δ 9.99（s, 1H）, 7.77 (s, 1H), 7.49 (s, 2H), 7.14 (s, 1H), 3.85 (s, 1H), 2.50 （s, 6H）, 2.21-2.06 (m, 2H), 1.86-1.66 (m, 3H), 1.36-1.04 (m, 4H). ^{13}C NMR (300 MHz, $CDCl_3$) δ 184.3, 180.0, 169.4, 162.5, 141.8, 134.8, 121.6, 116.6, 83.3, 66.3, 54.9, 54.2, 34.7, 24.6, 21.4. HRMS (ESI): calcd for $C_{18}H_{22}Cl_2N_3O_2$ $[M+H]^+$, 382.1089; found, 382.1084.



1f White solid; ^{1}H NMR(300MHz,DMSO-d6,303K) δ 10.44（s,1H）, 8.15 (d, *J*=9Hz, 1H), 8.083 (s, 1H), 7.65 (s, 1H), 7.31-7.19 (m, 4H), 5.61 (d, *J*=3.6 Hz, 1H), 5.51 (dd, *J*=9 Hz, *J*=5.1 Hz, 1H), 4.59 (d, *J*=3.3 Hz, 1H), 3.14 (dd, *J*=15Hz, J=4.5Hz, 1H), 2.87 (d, *J*= 15Hz, 1H). ^{13}C NMR (300 MHz, $CDCl_3$) δ 184.9, 180.7, 169.8, 162.9, 141.4, 140.7, 131.6 (q, J_{F-C}=32.7Hz), 128.3, 126.9, 125.3, 124.5, 123.8 (q, J_{F-C}=271.1Hz), 118.0, 114.8, 72.4, 61.5, 39.7. HRMS(ESI): calcd for $C_{18}H_{21}F_3N_3O_2$ $[M+H]^+$, 368.1586; found, 368.1580. HRMS (ESI): calcd for $C_{21}H_{15}F_6N_2O_3$ $[M+Na]^+$, 479.0807; found, 479.0801.

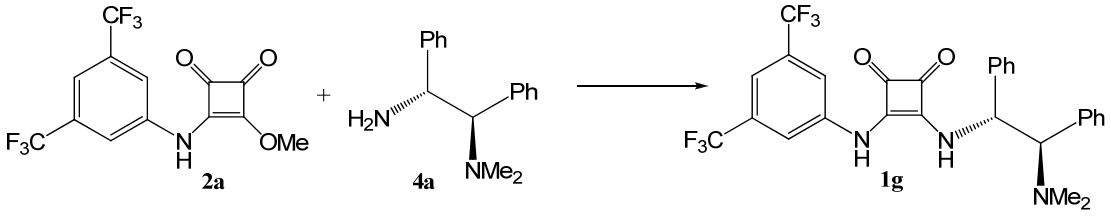
Catalyst 1e[2]:



A solution of **3a** (210mg, 0.5mmol), diisopropylethylamine (DIPEA) (182 μ l, 1.1mmol), and 1,5-dibromopentane (0.55mmol) in DMF(3 ml) was stirred at 45°C . After stirring for 24h, the reaction was quenched by the addition of water (15 ml), and the aqueous layer was extracted with ethyl acetate. Then, the combined organic phase was washed with brine, and dried over magnesium sulfate. After removal of the solvent under reduced pressure, the residue was purified by column chromatography using silica gel to give the adduct **1e.**

Yellow solid; ^{1}H NMR(300MHz,DMSO-d6,303K) 10.1 (s, 1H), 7.9 (s , 2H), 7.7 (s, 1H), 7.6 (s, 1H), 3.9 (s, 2H), 1.23-2.26 (m,10H); ^{13}C NMR (300 MHz,$CDCl_3$) δ 180.2, 170.4, 161.8, 141.4, 131.5 (q, $J_{F\text{-}C}$=32.7Hz), 123.8 (q, $J_{F\text{-}C}$=271.1Hz),118.1, 114.7, 68.4, 54.6, 49.6, 34.0, 26.5, 24.9, 24.6, 24.5, 23.5. HRMS (ESI): calcd for $C_{23}H_{26}F_6N_3O_2$ $[M+H]^+$, 489.1929; found, 489.1924.

Catalyst 1g:



To a solution of 3-(3, 5-bis(trifluoromethyl)phenylamino)-4-methoxycyclobut-3-ene-1,2-dione (0.422g) **2a** in 10 ml CH_3OH was added the solution of (1S,2S)-N',N'-dimethyl-1,2-diphenylethane-1,2-diamine **4a** (0.299g) in 3ml CH_3OH dropwise under the stirring at room temperature. The precipitate appeared quickly. When TLC indicated that the end of the reaction, filtrate the solid and dry them in the vacuum to obtain the product **1g**. white solid, ^{1}H NMR(300MHz,DMSO-d6,303K) δ 10.3 (s, 1H), 8.44 (s , 1H), 8.06 (s, 2H), 7.66 (s, 1H), 7.26 (t, *J*= 7.5Hz, 4H), 7.19 (d, *J*=3.27Hz_Z, 5H), 7.10 (t, *J*= 7.2Hz_Z, 1H), 5.78 (t, *J*=9.5Hz_Z, 1H), 4.20 (d, *J*= 11.4Hz_Z, 1H), 2.13 (s, 6H); ^{13}C NMR (300 MHz,$CDCl_3$) δ 184.7, 180.3, 169.1, 162.7, 141.2, 140.6, 132.5, 131.4(q, $J_{F\text{-}C}$=32.7Hz_Z), 129.6, 129.2, 127.8, 127.7, 127.5, 127.3, 123.8(q, $J_{F\text{-}C}$=271.1Hz_Z), 118.3, 114.8, 71.2, 58.1, 40.6. HRMS(ESI): calcd for $C_{28}H_{24}F_6N_3O_2$ $[M+H]^+$, 548.1772; found, 548.1767.

General procedure for the synthesis of N-sulfonyl imines

N-sulfonyl imines **1e**[4]**, 1h**[4] **and 1a-1d**[5], **1f**[5], **1g**[5] were synthesized according to literature procedures.

Preparation of N-sulfonyl imine **1i**:

A mixture of *p*-Toluenesulfonamide (1.71g, 10mmol), sodium *p*-Tolenesulfinate (1.78g, 10mmol) and Sulfamic acid (1.94g, 20mmol) was dissolved in MeOH/H_2O

(1:1, v/v, 15ml), then 4-isopropylbenzaldehyde 1.51ml (10mmol) was added in one portion. The reaction mixture was stirred over night at room temperature. The resulting white precipitate was collected by filtration, washed with water and hexane, and then dissolved in CH_2Cl_2 (50ml), added saturated aqueous $NaHCO_3$ solution (50ml), the mixture was continual stirred for 2 hours at room temperature. The organic phase was collected and concentrated to obtain the white imine product **1i.**

^{1}H NMR (300 MHz,CDCl3) δ 8.99 (s, 1H), 7.34-7.89(m, 4H), 7.26-7.32 (m, 4H), 2.89-3.04 (m, 1H), 2.42 (s, 1H), 1.25-1.27 (d, *J* = 7.6 Hz, 6H); ^{13}H NMR (300 MHz,DMSO-d_6) δ135.3, 131.7, 131.3, 130.1, 129.4, 127.7, 127.5, 125.8, 33.9, 23.4, 21.2.

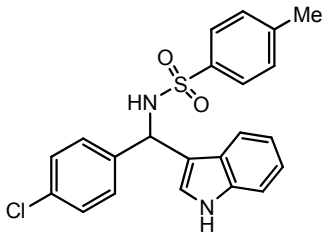
The general synthetic procedure of **1l** and **1m** followed the above method.

General procedure for asymmetric Friedel-Crafts reaction of addition of indoles to N-sulfonyl imines

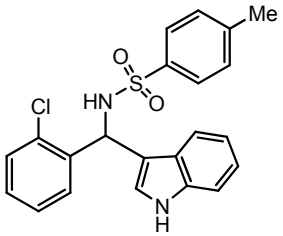
To a mixture of N-sulfonyl imines **1** (0.4mmol), squaraminde catalyst (2.5 mol %) in THF (0.1mL) was added indoles (0.1mmol) in one portion. The solution was heated to 50 ^{o}C and kept at this temperature for a specified reaction time. (Table **4**) When the reaction was complete, the reaction mixture was purified by chromatography (petroleum ether/ethyl acetate = 3/1) to afford the product.

Reference

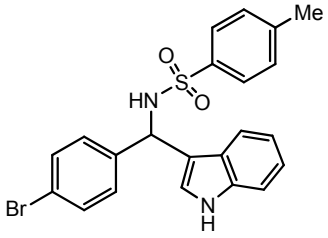
[1]. JP. Malerich, K. Hagihara, VH. Rawal, *J. Am. Chem. Soc*., **2008**, *130*, 14416-14417
[2]. T. Arai, M. Watanabe, A. Yanagisawa, *org. Lett*., **2007**, *9(18)*, 3595-3597
[3]. M. Kaik, J. Gawroński, *Tetrahedron: Asymmetry* **2003**, *14*, 1559-1563
[4]. R. Fan, D. Pu, F, Wen, Y. Ye, X. Wang, *J. Org. Chem*., **2008**, *73*, 3623-3625
[5]. Z. Li, X. Ren, P. Wei, H. Wan, Y. Shi, P. Ouyang, *Green Chem.*, **2006**, *8*,433-436



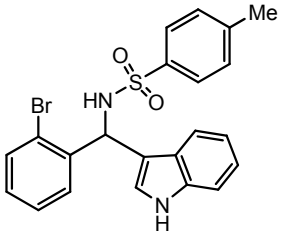
(**entry1**, **Table 4**) This product was obtained as a colorless solid in 94% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 95.5% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 1.0ml/min, λ = 254nm, t (major) = 17.87min, t (minor) = 47.00min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ 2.39 (s, 3H), 5.05 (d, *J* = 6.57 Hz, 1H), 5.82 (d, *J* = 6.57 Hz, 1H), 6.64 (s, 1H), 6.99 (t, *J* = 7.3 Hz, 1H), 7.13-7.32(m, 9H), 7.56 (d, *J* = 8.3 Hz, 2H), 8.00 (brs, 1H); ^{13}C NMR (300 MHz,$CDCl_3$) δ21.5, 54.5, 111.4, 116.0, 119.1, 120.2, 122.8, 123.7, 125.2, 127.2, 128.5, 128.7, 129.4, 133.3, 136.6, 137.4, 138.9, 143.3;



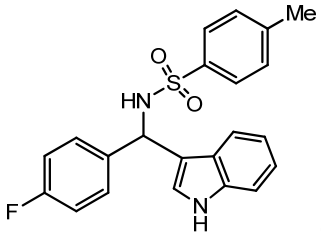
(entry2, Table4): This product was obtained as a colorless solid in 91% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 94% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.6ml/min, λ = 254nm, t (major) = 20.38 min, t (minor) = 64.38min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ 2.4 (s, 3H), 5.14 (d, *J* = 6.03 Hz, 1H), 6.19 (d, *J* = 5.85 Hz, 1H), 6.53 (d, *J* = 2.01 Hz, 1H), 6.98-7.31 (m, 8H), 7.43 (d, *J* = 7.86 Hz, 1H), 7.51 (d, *J* = 7.68 Hz, 1H), 7.68 (d, *J* = 8.25 Hz, 2H), 7.99 (brs, 1H); ^{13}C NMR (300 MHz,$CDCl_3$) δ21.4, 52.1, 111.3, 115.0, 119.0, 120.0, 122.6, 123.9, 125.4, 126.8, 127.3, 128.4, 128.9, 129.4, 129.6, 132.7, 136.5, 137.0, 137.9, 143.3;



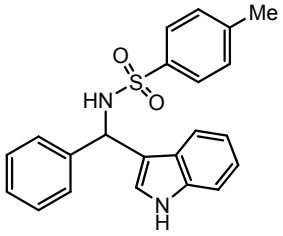
(entry3, table4): This product was obtained as a colorless solid in 92% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 96% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.8ml/min, λ = 254nm, t (major) = 24.91 min, t (minor) = 46.61min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ 2.39 (s, 3H) 5.10 (d, *J* = 4.05 Hz, 1H), 5.80 (d, *J* = 4.05 Hz, 1H), 6.63 (d, *J* = 1.29 Hz, 1H), 7.00 (t, *J* = 4.2 Hz, 1H),7.11-7.13 (m, 4H), 7.17 (t, *J* = 4.23 Hz, 1H), 7.22(d, *J* = 4.77 Hz, 1H), 7.27-7.32 (m, 3H), 7.55 (d, *J* = 4.95 Hz, 2H), 8.00 (brs, 1H); ^{13}C NMR (300 MHz,$CDCl_3$) δ21.5, 54.6, 111.4, 115.9, 119.2, 120.2, 122.8, 123.7, 125.2, 127.2, 129.1, 129.4, 129.7, 131.4, 136.6, 137.4, 139.4, 143.3;



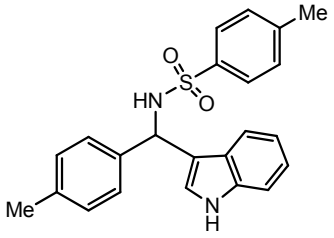
(entry4, table4): This product was obtained as a colorless solid in 92% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 93% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =70/30, 0.5ml/min, λ = 254nm, t (major) = 14.57 min, t (minor) = 37.53min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ 2.39 (s, 3H), 5.19 (d, *J* = 6.21 Hz, 1H), 6.22 (d, *J* = 6.39 Hz, 1H), 6.56 (d, *J* = 2.01 Hz, 1H), 7.00 (t, *J* = 7.32 Hz, 1H), 7.13-7.30 (m, 8H), 7.49 (t, *J* = 4.38 Hz, 1H), 7.65 (d, *J* = 8.22 Hz, 2H), 8.00 (brs, 1H); ^{13}C NMR (300 MHz,$CDCl_3$) δ21.4, 54.2, 111.3, 114.9, 118.9, 119.9, 122.6, 122.9, 124.1, 125.4, 126.3, 127.3, 128.9, 129.4, 132.8, 136.4, 136.9, 139.4, 143.3;



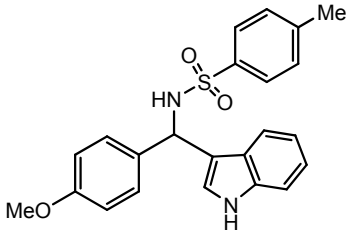
(entry 5 , table 4): This product was obtained as a colorless solid in 90% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 92% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =70/30, 0.6ml/min, λ = 254nm, t (major) =17.19 min, t (minor) = 28.56min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ2.38 (s, 3H), 5.17 (brs, 1H), 5.83 (d, *J* = 6.78 Hz, 1H), 6.65 (s, 1H), 6.88 (t, *J* = 8.22 Hz, 2H), 7.00 (t, *J* = 7.32 Hz, 1H),7.11-7.32 (m, 7H),7.56 (d, *J* = 8.04 Hz, 2H), 8.02 (s, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.5, 54.5, 111.4, 116.2, 119.2, 120.1, 122.6, 123.7, 125.3, 127.2, 128.9, 129.0, 129.3, 129.7, 136.2, 136.6, 137.5, 143.2;



(entry6 table4): This product was obtained as a colorless solid in 88% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 95% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.6ml/min, λ = 254nm, t (major) = 28.25 min, t (minor) = 62.14min]. ^{1}H NMR (300M Hz, $CDCl_3$) δ2.44(s, 3H), 5.07 (d, *J* = 6.75 Hz, 1H), 5.85 (d, *J* = 6.93 Hz, 1H), 6.80-7.51(m,11H), 7.58 (d, *J* = 8.25 Hz, 2H), 7.89 (s, 1H). ^{13}C NMR (300MHz, $CDCl_3$) δ22.3, 55.0, 111.3, 116.1, 119.1, 119.7, 122.3, 123.9, 126.3, 127.0, 127.2, 128.2, 129.1, 129.6, 136.5, 137.3, 140.2, 142.9, 143.4;

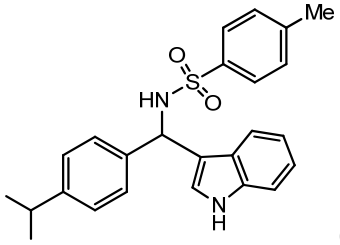


(entry 7, table 4); This product was obtained as a colorless solid in 86% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 91% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.6ml/min, λ = 254nm, t (major) = 25.96 min, t (minor) = 55.32min]. ^{1}H NMR (300M Hz, $CDCl_3$) δ2.29 (s, 3H) 2.37 (s, 3H), 5.11 (d, *J* = 6.78 Hz, 1H), 5.79 (d, *J* = 6.57 Hz, 1H), 6.71 (s, 1H), 6.98-7.29 (m, 10H), 7.55 (d, *J* = 7.68 Hz, 2H), 8.00 (s, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.0, 21.5, 54.9, 111.2, 116.5, 119.3, 119.8, 122.4, 123.7, 125.4, 127.1, 128.9, 129.1, 136.6, 137.0, 137.3, 137.6, 142.9;

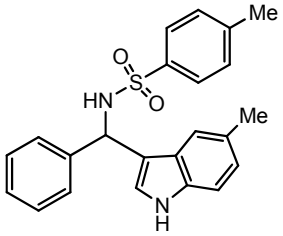


(entry8, table4): This product was obtained as a colorless solid in 89% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 93% ee as

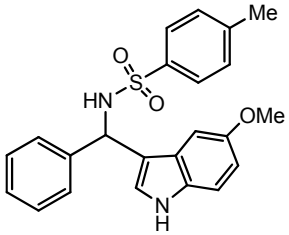
determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =60/40, 0.6ml/min, λ = 254nm, t (major) =14.69 min, t (minor) = 27.61min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ2.36 (s, 3H), 3.75 (s, 3H), 5.19 (s, 1H), 5.80 (d, *J* = 4.20 Hz, 1H), 6.75 (d, *J* = 1.29 Hz, 1H), 6.9-7.7 (m, 12H), 8.04 (brs, 1H);; ^{13}C NMR (300M Hz, $CDCl_3$) δ21.5, 54.7, 55.3, 111.2, 113.7, 116.7, 119.4, 119.9, 122.5, 123.6, 126.5, 127.2, 129.2, 129.7, 136.7, 139.2, 142.9, 143.6, 158.9;



(entry9, table4): This product was obtained as a colorless solid in 87% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 94% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =70/30, 0.7ml/min, λ = 254nm, t (major) = 11.93 min, t (minor) = 27.26 min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ 1.21-1.24 (d, *J* = 6.96 Hz, 6H), 2.34 (s, 3H), 2.79-2.88 (m, 1H), 5.11 (brs, 1H), 5.82-5.84 (d, *J* = 7.14 Hz, 1H), 6.69 (s, 1H), 6.91-7.35 (m, 10H), 7.50-7.52 (d, *J* = 8.25 Hz, 2H), 7.97 (brs, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.4, 23.9, 33.7, 54.9, 111.2, 116.4, 119.4, 119.8, 122.4, 123.7, 125.5, 126.2, 127.1, 127.2, 129.1, 129.6, 137.4, 137.5, 142.7, 147.9; HRMS(ESI): calcd for $C_{25}H_{27}N_2O_2S$ $[M+Na]^+$, 441.1613; found, 441.1607.

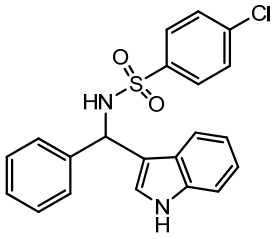


(entry10, table4): This product was obtained as a colorless solid in 92% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 91% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =70/30, 0.8ml/min, λ = 254nm, t (major) =10.27 min, t (minor) = 30.26min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ2.31 (s, 3H), 2.39 (s, 3H), 4.99 (d, *J* = 6.21 Hz, 1H), 5.80 (d, *J* = 6.39 Hz, 1H), 6.57 (d, *J* = 2.37 Hz, 1H), 6.87-7.31 (m, 10H), 7.79 (d, *J* = 8.22 Hz, 2H), 7.89 (brs, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.3, 21.4, 54.8, 110.9, 115.8, 118.5, 124.1, 125.5, 126.4, 127.0, 127.1, 128.2, 128.9, 129.3, 129.7, 134.7, 137.5, 140.5, 143.0;

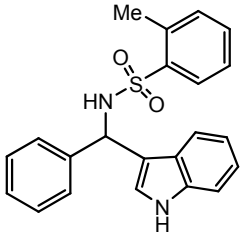


(entry11, table4): This product was obtained as a colorless solid in 96% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 92.5% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.6ml/min, λ = 254nm, t (major) =22.85 min, t (minor) = 46.25min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ2.44 (s, 3H), 3.74 (s, 3H), 5.10 (d, *J* = 6.78 Hz, 1H), 5.85 (d, *J* = 6.93 Hz, 1H), 6.63 (d, *J* = 2.04 Hz, 1H), 6.82-7.33 (m, 10H), 7.58 (d, *J* = 8.22 Hz, 2H), 7.90 (brs, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.5, 55.1, 55.8,

101.1, 111.9, 112.9, 116.2, 124.5, 126.5, 127.2, 127.4, 128.3, 129.2, 129.7, 131.6, 137.7, 140.3, 142.9, 154.3;



(entry12, table4): This product was obtained as a colorless solid in 85% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 84% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =70/30, 0.8ml/min, λ = 254nm, t (major) =12.12 min, t (minor) = 27.00min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ5.13 (d, *J* = 6.57 Hz, 1H), 5.92 (d, *J* = 6.78 Hz, 1H), 6.67 (d, *J* = 2.22 Hz, 1H), 7.05 (d, *J* = 7.14 Hz, 1H), 7.17-7.38 (m, 10H), 5.13 (d, *J* = 8.61 Hz, 2H), 7.98 (brs, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ55.3, 111.3, 115.9, 119.3, 120.2, 122.7, 123.8, 125.3, 127.2, 127.6, 128.4, 128.5, 128.7, 136.6, 138.6, 139.1, 139.7;



(entry13, table4): This product was obtained as a colorless solid in 88% yield after chromatography (silica gel: petroleum ether/ethyl acetate = 3/1) and 90% ee as determined by HPLC [Daicel Chiralcel OD-H, Hexanes/ IPA =80/20, 0.6ml/min, λ = 254nm, t (major) =40.17 min, t (minor) = 52.45min]. ^{1}H NMR (300 MHz,$CDCl_3$) δ2.40 (s, 3H), 5.15 (d, *J* = 6.96 Hz, 1H), 5.81 (d, *J* = 6.93 Hz, 1H), 6.71 (d, *J* = 2.37 Hz, 1H), 6.99-7.47 (m, 13H), 8.03 (brs, 1H); ^{13}C NMR (300M Hz, $CDCl_3$) δ21.0, 55.1, 111.3, 116.0, 119.2, 119.9, 122.5, 123.7, 125.2, 125.9, 127.0, 127.4, 128.2, 129.6, 132.1, 132.4, 136.6, 136.9, 138.2, 140.1;