

Facile Synthesis of Multiply Substituted Aryl Sulfones via a [3+3] Benzannulation Strategy

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Supporting Information

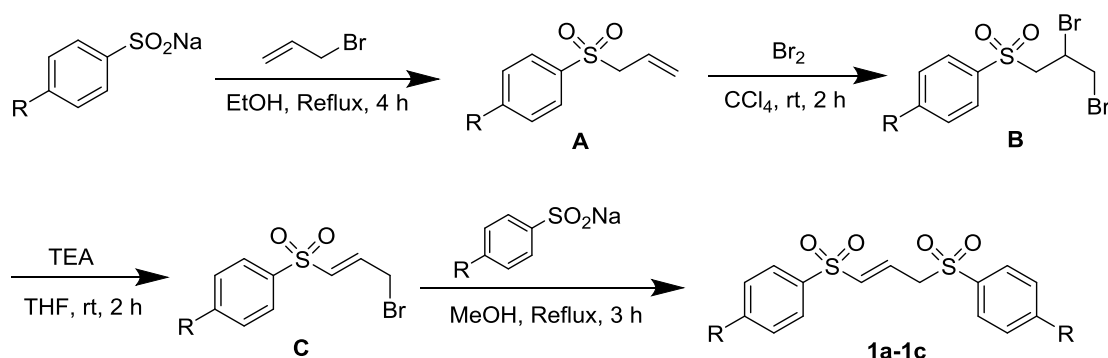
I.	General information.....	2
II.	Synthesis of substrates.....	2
III.	General synthetic procedures of products 3a-3t, 5, 7.....	8
IV.	Typical procedure for the synthesis of products 8-11.....	15
V.	References.....	17
VI.	Copies of NMR spectra.....	18

I. General information

^1H NMR and ^{13}C NMR spectra were recorded on a 400 MHz spectrometer. Chemical shifts of protons are reported in parts per million downfield from tetramethylsilane. Chemical shifts of carbon are referenced to the carbon resonances of the solvent (CDCl_3 ; δ 77.0). Peaks are labeled as single (s), broad singlet (bs), doublet (d), triplet (t), double doublet (dd), multiplet (m). Melting points were determined with a commercially available melting point apparatus. IR spectra were recorded on a PerkinElmer FT-IR spectrometer. Data are represented as follows: frequency of absorption (cm^{-1}). High-resolution mass spectra (HRMS) were acquired using an electron spray ionization time-of flight (ESI-TOF) mass spectrometer in positive mode. All reagents were used without further purification as received from commercial suppliers unless otherwise noted. All solvents were dried and distilled prior to use according to the standard protocols. 1,3-Bis(sulfonyl)propenes and β,γ -unsaturated α -ketoesters were prepared according to the reported procedure.^[1-4]

II. Synthesis of substrates

(1) General procedure for the synthesis of 1,3-bis(sulfonyl)propenes 1a-1c^[1]



1a as an example: To a solution of sodium 4-methylbenzenesulfinate (14.7 g, 82.6 mmol) in ethanol (60 mL) was added 3-bromoprop-1-ene (10.0 g, 82.7 mmol) under argon atmosphere. The reaction mixture was refluxed for 4 h and then the solvent was removed. The left residue was added water (50 mL) and then extracted with CH_2Cl_2 (3×25 mL). The combined organic phases were washed with saturated brine, dried over anhydrous Na_2SO_4 and concentrated in vacuum. The crude product **A** (14.1 g, 87%) was used directly without further purification.

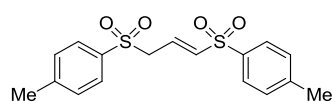
To a solution of **A** (14.1 g, 71.9 mmol) in CCl_4 (26 mL) was added a solution of Br_2 (12.1 g, 75.5 mmol) in CCl_4 (10 mL) dropwise. The reaction mixture was stirred at room temperature for 2 h. After the completion of the reaction, the reaction mixture was quenched by saturated aqueous NaHSO_3 solution and then extracted with CH_2Cl_2 (25 mL \times 3). The combined organic phases were washed with saturated brine, dried over anhydrous Na_2SO_4 and concentrated in vacuum. The crude product **B** (21.5 g, 84%) was used for the next step without further purification.

Et_3N (6.4 g, 63.4 mmol) was added dropwise to a stirred solution of **B** (21.5 g, 60.4 mmol) in dry THF (40 mL) at 0 $^\circ\text{C}$. The reaction mixture was stirred under the same temperature for 2 h. After completion of the reaction, the solvent was removed. The residue was added water (50 mL) and then extracted with CH_2Cl_2 (3×25 mL). The combined organic phases were washed with saturated

brine, dried over anhydrous Na₂SO₄ and concentrated in vacuum. The crude product was purified by flash chromatography (petroleum ether/ethyl acetate = 30:1) to give the expected compound **C** (11.8 g, 71%) as a white solid.

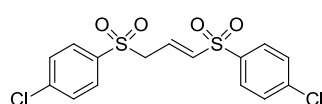
A mixture of **C** (5.3 g, 19.2 mmol) and sodium 4-methylbenzenesulfinate (6.8 g, 38.4 mmol) in CH₃OH (30 mL) was stirred at reflux for 3 h. The solvent was removed and the residue was redissolved in CH₂Cl₂ (60 mL). The organic phase was washed with water and brine, dried over anhydrous Na₂SO₄, filtered, and concentrated in vacuum. The crude product was purified by flash chromatography (petroleum ether/ethyl acetate = 5:1) to give the product **1a** (4.2 g, 62%) as a white solid.

(E)-4,4'-(prop-1-ene-1,3-diylbisulfonyl)bis(methylbenzene) (1a):



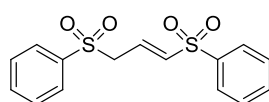
White solid; 4-steps, 30% yield; mp = 148.9-151.1 °C; ¹H NMR (400 MHz, DMSO) δ 7.63 (m, 4H), 7.47 (d, *J* = 8.1 Hz, 2H), 7.35 (d, *J* = 8.1 Hz, 2H), 6.80 (d, *J* = 14.9 Hz, 1H), 6.54 (dt, *J* = 15.0, 7.6 Hz, 1H), 4.39 (d, *J* = 7.6 Hz, 2H), 2.44 (s, 3H), 2.36 (s, 3H); ¹³C NMR (101 MHz, DMSO) δ 145.21, 145.16, 138.49, 136.76, 135.44, 132.56, 130.62, 130.32, 128.26, 127.94, 56.85, 21.56, 21.52.

(E)-4,4'-(prop-1-ene-1,3-diylbisulfonyl)bis(chlorobenzene) (1b):



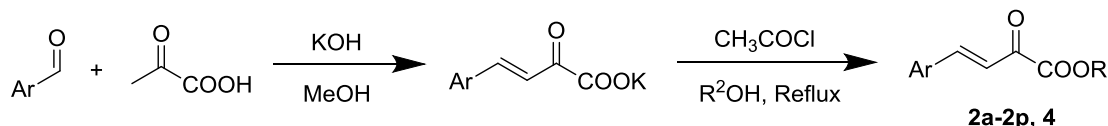
White solid; 4-steps, 21% yield; mp = 146.6-148.3 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.74 (m, 4H), 7.57 (d, *J* = 8.7 Hz, 2H), 7.47 (d, *J* = 8.6 Hz, 2H), 6.83 (dt, *J* = 15.3, 7.7 Hz, 1H), 6.41 (d, *J* = 15.1 Hz, 1H), 3.97 (dd, *J* = 7.7, 0.9 Hz, 2H); ¹³C NMR (101 MHz, CDCl₃) δ 141.40, 140.97, 138.58, 137.71, 136.07, 131.54, 129.89, 129.82, 129.76, 129.38, 57.78.

(E)-(prop-1-ene-1,3-diylbisulfonyl)dibenzene (1c):



White solid; 4-steps, 39% yield; mp = 103.5-105.4 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.82 (d, *J* = 7.2 Hz, 2H), 7.76 (dd, *J* = 8.4, 1.1 Hz, 2H), 7.66 (m, 1H), 7.61 (d, *J* = 7.5 Hz, 1H), 7.56 (t, *J* = 7.7 Hz, 2H), 7.47 (t, *J* = 7.8 Hz, 2H), 6.80 (dt, *J* = 15.3, 7.8 Hz, 1H), 6.37 (d, *J* = 15.1 Hz, 1H), 3.94 (dd, *J* = 7.7, 1.1 Hz, 2H); ¹³C NMR (101 MHz, CDCl₃) δ 139.37, 138.61, 137.71, 134.34, 133.92, 131.36, 129.47, 129.42, 128.31, 127.94, 57.76.

(2) General procedure for the synthesis of β,γ-unsaturated α-ketoesters 2a-2p, 4^[2]

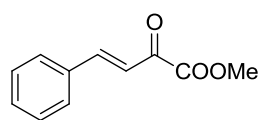


2a as an example: To a solution of benzaldehyde (10.6 g, 0.1 mol) and pyruvic acid (8.8 g, 0.1 mol) in MeOH (8 mL) was added a solution of KOH (8.4 g, 0.15 mol) in MeOH (30 mL) at 0 °C. The first 1 equiv. of the base solution were added dropwise and the reaction temperature was kept under 25 °C. The ice bath was then removed and the rest of the base solution was added quickly. The reaction mixture was stirred at 40 °C for 1 h and then 0 °C overnight. The precipitate was

collected by filtration, washed twice with chilled MeOH, once with Et₂O and dried under vacuum to furnish the potassium salt (15.6 g, 73%) as yellow solid.

Acetyl chloride (18.0 g, 230.0 mmol) was added dropwisely to the corresponding alcohol in an ice-water bath to produce hydrochloric acid. Potassium salt (4.3 g, 20.0 mmol) was then added and the mixture stirred for 30 min before the ice bath was removed. After stirred at room temperature for 2 h, the mixture was refluxed overnight. Then the solvent was removed and the yellow residue was added water (50 mL) and then extracted with CH₂Cl₂ (3×25 mL). The combined organics were washed with saturated NaHCO₃ and brine, dried over anhydrous Na₂SO₄ and concentrated in vacuum. The crude product was purified by flash chromatography (petroleum ether/ethyl acetate = 30:1) to give the product **2a** (2.1 g, 56%) as a yellow solid.

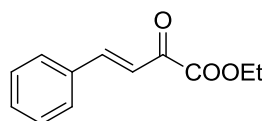
(E)-Methyl 2-oxo-4-phenylbut-3-enoate (2a):



53.01.

Yellow solid; 2-steps, 41% yield; mp = 74.6-76.6 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.90 (d, *J* = 16.1 Hz, 1H), 7.66 (d, *J* = 6.9 Hz, 2H), 7.46 (m, 3H), 7.39 (d, *J* = 16.1 Hz, 1H), 3.96 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.44, 162.58, 148.65, 134.03, 131.69, 129.11, 129.07, 120.53,

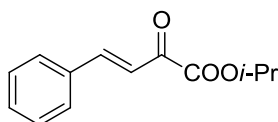
(E)-Ethyl 2-oxo-4-phenylbut-3-enoate (2b):



129.08, 129.02, 120.65, 62.48, 14.07.

Yellow oil; 2-steps, 32% yield; ¹H NMR (400 MHz, CDCl₃) δ 7.79 (d, *J* = 16.1 Hz, 1H), 7.56 (dd, *J* = 7.5, 1.7 Hz, 2H), 7.40-7.32 (m, 3H), 7.28 (d, *J* = 16.1 Hz, 1H), 4.32 (q, *J* = 7.1 Hz, 2H), 1.34 (t, *J* = 7.1 Hz, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.89, 162.24, 148.40, 134.07, 131.60,

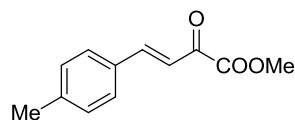
(E)-Isopropyl 2-oxo-4-phenylbut-3-enoate (2c):



129.09, 129.00, 120.79, 70.67, 21.67.

Yellow oil; 2-steps, 21% yield; ¹H NMR (400 MHz, CDCl₃) δ 7.84 (d, *J* = 16.1 Hz, 1H), 7.63 (dd, *J* = 7.5, 1.8 Hz, 2H), 7.46-7.39 (m, 3H), 7.33 (d, *J* = 16.1 Hz, 1H), 5.34-5.10 (m, 1H), 1.40 (d, *J* = 6.3 Hz, 6H); ¹³C NMR (101 MHz, CDCl₃) δ 183.32, 161.92, 148.23, 134.12, 131.55,

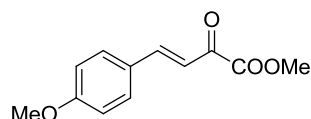
(E)-Methyl 2-oxo-4-(p-tolyl)but-3-enoate (2d):



142.57, 131.36, 129.88, 129.15, 119.54, 52.96, 21.64.

Yellow solid; 2-steps, 29% yield; mp = 85.1-87.6 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.87 (d, *J* = 16.1 Hz, 1H), 7.55 (d, *J* = 8.1 Hz, 2H), 7.34 (d, *J* = 16.1 Hz, 1H), 7.25 (d, *J* = 8.0 Hz, 2H), 3.95 (s, 3H), 2.41 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.46, 162.73, 148.77,

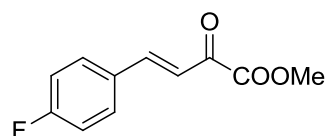
(E)-Methyl 4-(4-methoxyphenyl)-2-oxobut-3-enoate (2e):



3.87 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.28, 162.90, 162.71,

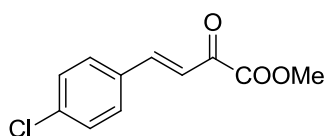
148.50, 131.09, 126.85, 118.20, 114.64, 55.47, 52.89.

(E)-Methyl 4-(4-fluorophenyl)-2-oxobut-3-enoate (2f):



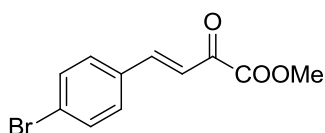
Yellow solid; 2-steps, 37% yield; mp = 92.3-94.7 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.84 (d, J = 16.1 Hz, 1H), 7.67-7.59 (m, 2H), 7.30 (d, J = 16.2 Hz, 1H), 7.17-7.09 (m, 2H), 3.94 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.16, 164.74 (d, J = 253.9 Hz), 162.49, 147.15, 131.12 (d, J = 8.8 Hz), 130.33 (d, J = 3.4 Hz), 120.19, 116.39 (d, J = 22.1 Hz), 53.03.

(E)-Methyl 4-(4-chlorophenyl)-2-oxobut-3-enoate (2g):



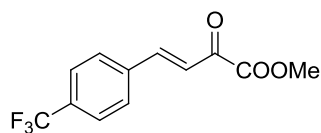
Yellow solid; 2-steps, 39% yield; mp = 118.1-119.6 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.82 (d, J = 16.1 Hz, 1H), 7.57 (d, J = 8.5 Hz, 2H), 7.40 (d, J = 8.5 Hz, 2H), 7.34 (d, J = 16.1 Hz, 1H), 3.94 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.13, 162.39, 146.96, 137.76, 132.50, 130.17, 129.46, 120.86, 53.09.

(E)-Methyl 4-(4-bromophenyl)-2-oxobut-3-enoate (2h):



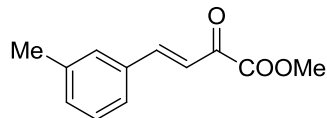
Yellow solid; 2-steps, 42% yield; mp = 124.7-126.6 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.80 (d, J = 16.1 Hz, 1H), 7.57 (d, J = 8.5 Hz, 2H), 7.49 (d, J = 8.5 Hz, 2H), 7.36 (d, J = 16.1 Hz, 1H), 3.94 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.14, 162.37, 147.03, 132.91, 132.43, 130.32, 126.23, 120.94, 53.10.

(E)-Methyl 2-oxo-4-(4-(trifluoromethyl)phenyl)but-3-enoate (2i):



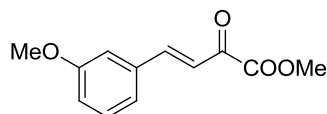
Yellow solid; 2-steps, 39% yield; mp = 121.6-123.1 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.88 (d, J = 16.2 Hz, 1H), 7.74 (d, J = 8.4 Hz, 2H), 7.69 (d, J = 8.4 Hz, 2H), 7.44 (d, J = 16.2 Hz, 1H), 3.95 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.04, 162.17, 146.25, 137.29, 133.06, 129.07, 126.05 (q, J = 3.8 Hz), 125.02, 122.62, 53.15.

(E)-Methyl 2-oxo-4-(m-tolyl)but-3-enoate (2j):



Yellow solid; 2-steps, 29% yield; mp = 55.7-57.1 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.86 (d, J = 16.1 Hz, 1H), 7.45 (d, J = 7.6 Hz, 2H), 7.36 (d, J = 16.1 Hz, 1H), 7.33-7.26 (m, 2H), 3.95 (s, 3H), 2.40 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.45, 162.64, 148.88, 138.84, 133.97, 132.59, 129.63, 128.99, 126.38, 120.31, 52.99, 21.27.

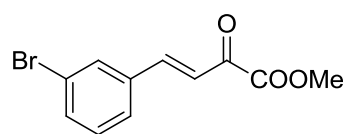
(E)-Methyl 4-(3-methoxyphenyl)-2-oxobut-3-enoate (2k):



Yellow solid; 2-steps, 21% yield; mp = 55.1-56.2 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.84 (d, J = 16.1 Hz, 1H), 7.38-7.29 (m, 2H), 7.23 (d, J = 7.6 Hz, 1H), 7.14 (d, J = 1.5 Hz, 1H), 7.01 (dd, J = 8.2, 1.7 Hz, 1H), 3.94 (s, 3H), 3.85 (s, 3H); ^{13}C NMR (101 MHz,

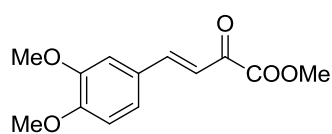
CDCl₃) δ 182.41, 162.57, 160.05, 148.59, 135.35, 130.09, 121.89, 120.76, 117.80, 113.57, 55.39, 53.01.

(E)-Methyl 4-(3-bromophenyl)-2-oxobut-3-enoate (2l):



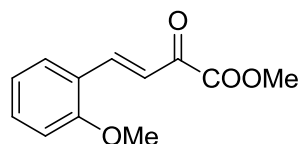
Yellow solid; 2-steps, 27% yield; mp = 127.6-129.1 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.81-7.75 (m, 2H), 7.60-7.52 (m, 2H), 7.36 (d, *J* = 16.1 Hz, 1H), 7.29 (m, 1H), 3.94 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.05, 162.26, 146.58, 136.06, 134.34, 131.52, 130.58, 127.64, 123.24, 121.66, 53.12.

(E)-Methyl 4-(3,4-dimethoxyphenyl)-2-oxobut-3-enoate (2m):



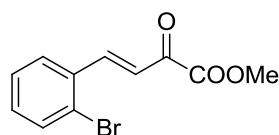
Yellow solid; 2-steps, 24% yield; mp = 115.7-117.8 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.83 (d, *J* = 16.0 Hz, 1H), 7.27-7.24 (m, 1H), 7.23-7.20 (m, 1H), 7.15 (d, *J* = 1.8 Hz, 1H), 6.90 (d, *J* = 8.3 Hz, 1H), 3.94 (bs, 9H); ¹³C NMR (101 MHz, CDCl₃) δ 182.12, 162.91, 152.59, 149.45, 148.77, 127.10, 124.65, 118.29, 111.18, 110.21, 56.05, 56.00, 52.93.

(E)-Methyl 4-(2-methoxyphenyl)-2-oxobut-3-enoate (2n):



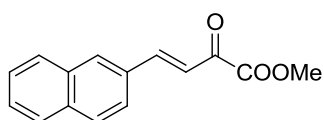
Yellow solid; 2-steps, 19% yield; mp = 46.4-47.8 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.21 (d, *J* = 16.3 Hz, 1H), 7.62 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.46-7.38 (m, 2H), 7.02-6.90 (m, 2H), 3.93 (s, 3H), 3.91 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 183.05, 162.97, 159.31, 144.15, 133.12, 129.55, 123.05, 120.95, 120.85, 111.36, 55.59, 52.89.

(E)-Methyl 4-(2-bromophenyl)-2-oxobut-3-enoate (2o):



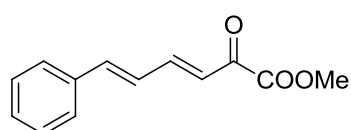
Yellow solid; 2-steps, 16% yield; mp = 54.3-57.4 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.26 (d, *J* = 16.1 Hz, 1H), 7.73 (dd, *J* = 7.8, 1.6 Hz, 1H), 7.65 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.37 (t, *J* = 7.6 Hz, 1H), 7.32-7.30 (m, 1H), 7.30-7.26 (m, 1H), 3.95 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.21, 162.37, 146.70, 134.00, 133.75, 132.40, 128.12, 127.86, 126.66, 122.98, 53.08.

(E)-Methyl 4-(naphthalen-2-yl)-2-oxobut-3-enoate (2p):



Yellow solid; 2-steps, 31% yield; mp = 109.8-111.9 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.07-7.99 (m, 2H), 7.86 (m, 3H), 7.75 (d, *J* = 8.6 Hz, 1H), 7.55 (m, 2H), 7.47 (d, *J* = 16.1 Hz, 1H), 3.95 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 182.33, 162.65, 148.65, 134.91, 133.24, 131.96, 131.58, 128.96, 128.89, 128.00, 127.86, 126.96, 123.61, 120.60, 53.01.

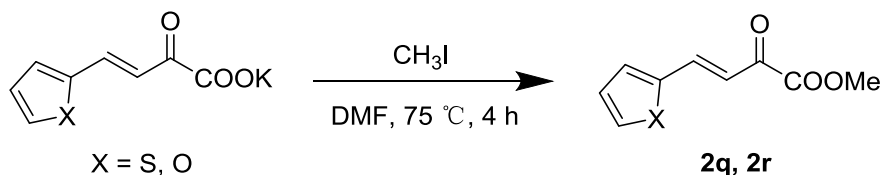
(3E, 5E)-Methyl 2-oxo-6-phenylhexa-3,5-dienoate (4):



Yellow solid; 2-steps, 17% yield; mp = 127.9-129.8 °C; ¹H NMR (400 MHz, CDCl₃) δ 7.65 (dd, *J* = 15.3, 10.9 Hz, 1H), 7.50 (m, 2H), 7.42-7.32 (m, 3H), 7.09 (d, *J* = 15.5 Hz, 1H), 6.97 (dd, *J* = 15.5, 10.9 Hz, 1H), 6.88 (d, *J* = 15.3 Hz, 1H), 3.91 (s,

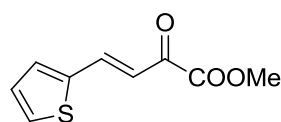
3H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.42, 162.61, 148.57, 144.75, 135.64, 129.93, 128.97, 127.69, 126.56, 123.98, 52.92.

(3) Preparation of β,γ -unsaturated α -ketoesters **2q**, **2r**^[2]



2q as an example: To a solution of potassium (E)-2-oxo-4-(thiophen-2-yl)but-3-enoate (3.3 g, 15.0 mmol) in DMF (40 mL) was added iodomethane (3.2 g, 22.5 mmol) under argon at room temperature. The reaction was stirred at 75 °C for 4 h and cooled to room temperature. The reaction solution was diluted with water (100 mL) and extracted with ethyl acetate (40 mL \times 3). The combined organic layers were washed with saturated brine, dried with anhydrous Na_2SO_4 and concentrated in vacuum. The crude product was purified by flash chromatography (petroleum ether/ethyl acetate = 30:1) to give the expected product **2q** (1.8 g, 62%) as a yellow solid.

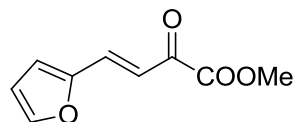
(E)-Methyl 2-oxo-4-(thiophen-2-yl)but-3-enoate (**2q**):



Yellow solid; 2-steps, 39% yield; mp = 106.1-107.9 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.01 (d, J = 16.3 Hz, 1H), 7.53 (d, J = 5.0 Hz, 1H), 7.44 (d, J = 3.7 Hz, 1H), 7.15 (m, 2H), 3.94 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 181.74, 162.46, 140.62, 139.72, 133.71, 131.01,

128.69, 119.25, 53.00.

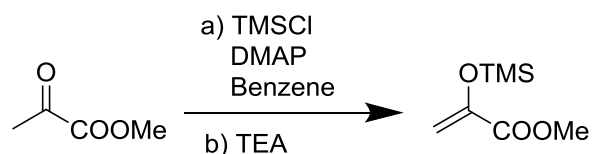
(E)-Methyl 4-(furan-2-yl)-2-oxobut-3-enoate (**2r**):



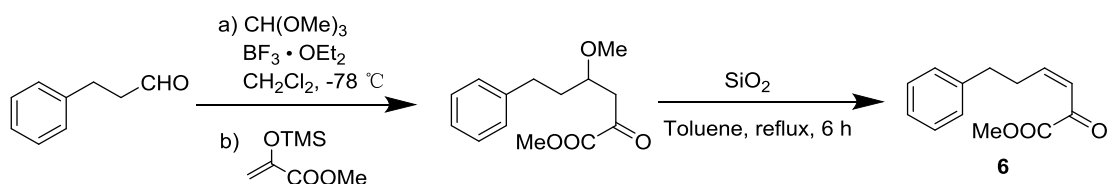
Yellow solid; 67% yield (1.8 g); mp = 64.2-66.7 °C; ^1H NMR (400 MHz, CDCl_3) δ 7.63 (d, J = 15.8 Hz, 1H), 7.58 (d, J = 1.5 Hz, 1H), 7.22 (d, J = 15.8 Hz, 1H), 6.83 (d, J = 3.5 Hz, 1H), 6.55 (dd, J = 3.5, 1.8 Hz, 1H), 3.92 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 181.98,

162.44, 151.09, 146.36, 133.66, 118.55, 118.09, 113.16, 52.93.

(4) Preparation of β,γ -unsaturated α -ketoester **6**^[3-4]

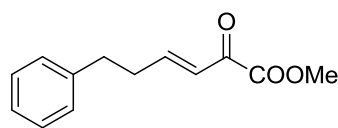


To a solution of methyl pyruvate (29.0 g, 0.28 mol) and DMAP (61.1 mg, 0.50 mmol) in dry benzene (60 mL) was added trimethylsilyl chloride (53.9 g, 0.50 mol). Triethylamine (57.5 g, 0.57 mol) was then added dropwise to the mixture, which was kept under gentle reflux by controlling the dropping rate. After the addition was complete, the mixture was refluxed for an additional 2 h. After cooling down of the mixture, a white precipitate of triethylamine hydrochloride was filtered off via a glass filter under a stream of argon. The solvent was removed under reduced pressure, and the residue was distilled to afford methyl 2-((trimethylsilyl)oxy)acrylate (11.2 g, 23%) as a colorless oil.



To a mixture of 3-phenylpropanal (2.7 g, 20.0 mmol) and trimethylorthoformate (2.2 g, 21.0 mmol) in anhydrous CH_2Cl_2 (20 mL) was added $\text{BF}_3 \cdot \text{OEt}_2$ (3.0 g, 21.0 mmol) dropwisely under Ar at -78°C . After 30 min, a solution of methyl 2-((trimethylsilyl)oxy)acrylate (3.5 g, 20.0 mmol) in CH_2Cl_2 (20 mL) was added dropwisely. Another 30 min, the reaction mixture was warmed to -30°C over 2 h and stirred for an additional 1 h at 0°C . Saturated NaHCO_3 was then added, and the mixture was extracted with CH_2Cl_2 . The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was dissolved in toluene (70 mL). Then silica gel for chromatography (20 g) was added and the mixture was refluxed with vigorous stirring for 6 h. After being cooled down to room temperature, the silica gel was filtered off and washed with diethyl ether several times. The filtrate was combined and concentrated under reduced pressure. The crude product was purified by flash chromatography (petroleum ether/ethyl acetate = 30:1) to give product **6** (1.1 g, 26% in two steps) as a yellow oil.

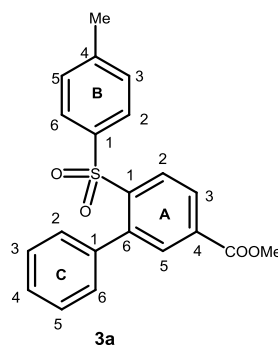
(E)-Methyl 4-(furan-2-yl)-2-oxobut-3-enoate (6):



Yellow oil; 26% yield in two steps from 3-phenylpropanal; ^1H NMR (400 MHz, CDCl_3) δ 7.29 (m, 2H), 7.25-7.15 (m, 4H), 6.67 (d, $J = 15.9$ Hz, 1H), 3.87 (s, 3H), 2.82 (t, $J = 7.7$ Hz, 2H), 2.63 (dd, $J = 14.5, 7.5$ Hz, 2H); ^{13}C NMR (101 MHz, CDCl_3) δ 182.84, 162.65, 153.71, 140.31, 128.58, 128.31, 126.36, 125.54, 52.83, 34.74, 34.05.

III. General synthetic procedures of products 3a-3t, 5, 7

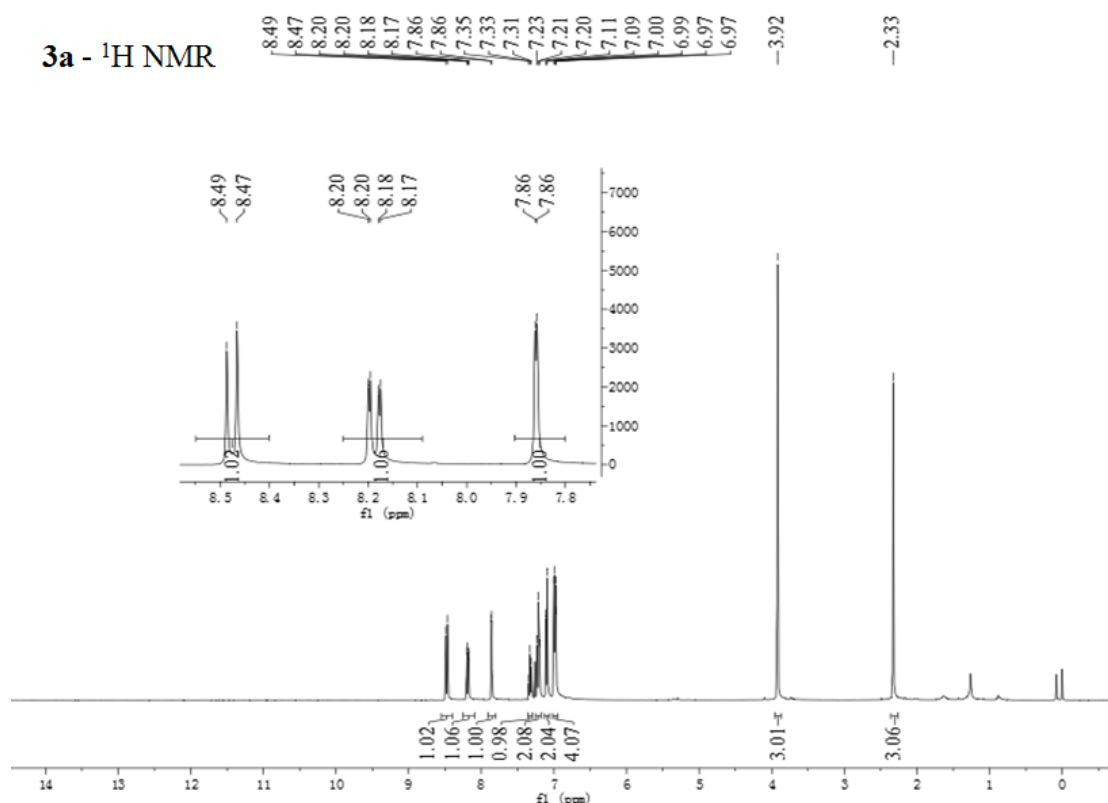
To a solution of 1,3-bis(sulfonyl)propene **1a** (73.6 mg, 0.21 mmol) and β,γ -unsaturated α -ketoester **2a** (38.0 mg, 0.2 mmol) in CHCl_3 (4 mL) was added DBU (36.6 mg, 0.24 mmol) under argon atmosphere. The reaction mixture was stirred at room temperature for 48 h and then was evaporated under reduced pressure. The residue was purified by flash column chromatography (petroleum ether/ethyl acetate = 20:1) to give the product **3a** (70.4 mg, 96%) as a white solid.

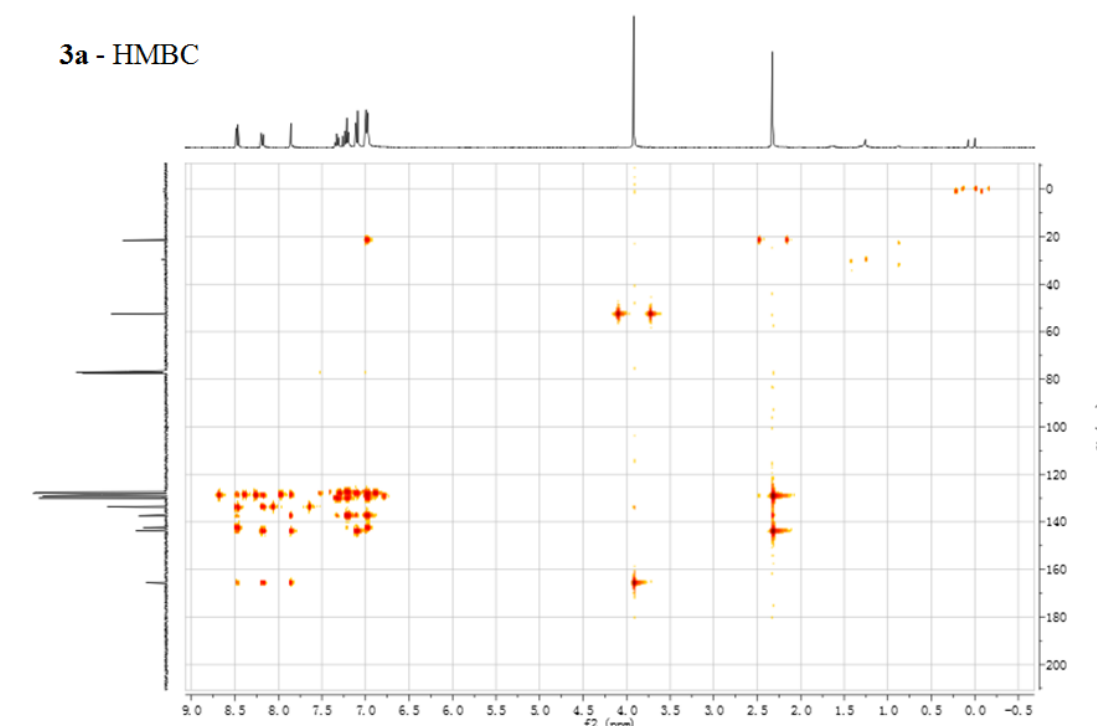


The structure of **3a** was firstly confirmed by HRMS (m/z of $(\text{M}+\text{H})^+ = 367.1008$). The ^1H

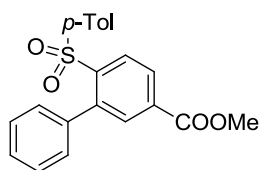
NMR spectrum of **3a** showed two adjacent aromatic H(A2) and H(A3) (δ 8.48, 8.19 ppm) with coupling constant of 8.3 Hz. In addition, the dd peak of H(A3) and second small coupling constant (1.7 Hz) indicated that it also couples with another more distant H(A5) ($J = 1.6$ Hz). Two triplets at δ 7.33, 7.21 ppm were assigned to H(C4) and H(C3, C5). The peak at 7.10 ppm ($J = 8.3$ Hz) was assigned to H(B2, B6). The overlapped peaks at 7.00-6.97 ppm belongs to H(B3, B5) and H(C2, C6). The signals at 3.92, 2.33 ppm were assigned to methyl ester (A4) and methyl (B4) respectively.

For the ^{13}C NMR spectrum of **3a**, the signal of δ 165.58 ppm was assigned to the carbonyl group (A4). The HMBC spectrum of **3a** showed that the carbonyl group has strong correlations with H(A3), H(A5) and weak correlation with H(A2). The result indicated that the ester group is at A4 position. The peaks at 143.85 and 143.83 ppm were assigned to C(A1) and C(B1). The peak at 142.40 ppm was assigned to C(A4). The electron-withdrawing sulfonyl group and ester group cause the shift of the signals to downfield. The eleven peaks between 137.39-127.37 ppm belongs to C(A2), C(A3), C(A5), C(B2-B6), and C(C2-C6). The peak at 52.60 was assigned to the methyl of ester group (A4). The peak at 21.52 ppm was assigned to the methyl (B4).



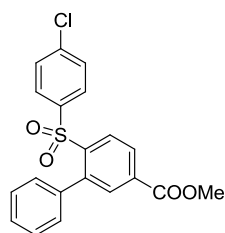


Methyl 6-tosyl-[1,1'-biphenyl]-3-carboxylate (3a):



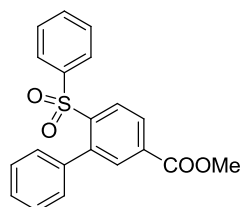
White solid; 96% yield (70.4 mg); mp = 125.5-126.8 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.48 (d, J = 8.3 Hz, 1H), 8.19 (dd, J = 8.3, 1.7 Hz, 1H), 7.86 (d, J = 1.6 Hz, 1H), 7.33 (t, J = 7.5 Hz, 1H), 7.21 (t, J = 7.6 Hz, 2H), 7.10 (d, J = 8.3 Hz, 2H), 6.98 (m, 4H), 3.92 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.58, 143.85, 143.83, 142.40, 137.39, 137.33, 133.86, 133.67, 129.97, 129.06, 128.76, 128.56, 127.95, 127.91, 127.37, 52.60, 21.52; HRMS (ESI) calcd for $\text{C}_{21}\text{H}_{19}\text{O}_4\text{S}$ ($\text{M}+\text{H}$) $^+$: 367.0999, found: 367.1008; IR (KBr): ν = 3062, 2959, 2919, 2851, 1736, 1306, 1237, 1156, 1093, 762, 658, 543 cm^{-1} .

Methyl 6-((4-chlorophenyl)sulfonyl)-[1,1'-biphenyl]-3-carboxylate (3b):



White solid; 97% yield (75.1 mg); mp = 124.5-126.0 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.49 (d, J = 8.3 Hz, 1H), 8.21 (dd, J = 8.3, 1.7 Hz, 1H), 7.88 (d, J = 1.6 Hz, 1H), 7.35 (t, J = 7.5 Hz, 1H), 7.24 (t, J = 7.6 Hz, 2H), 7.14 (m, 4H), 6.98 (d, J = 7.0 Hz, 2H), 3.93 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.40, 143.21, 142.36, 139.59, 138.70, 137.13, 134.28, 133.70, 130.01, 129.27, 128.76, 128.70, 128.18, 127.55, 52.66; HRMS (ESI) calcd for $\text{C}_{20}\text{H}_{16}\text{O}_4\text{SCl}$ ($\text{M}+\text{H}$) $^+$: 387.0452, found: 387.0449; IR (KBr): ν = 3104, 3062, 2992, 2958, 2922, 1724, 1319, 1155, 1086, 756, 634, 557 cm^{-1} .

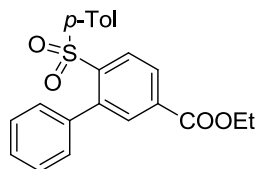
Methyl 6-(phenylsulfonyl)-[1,1'-biphenyl]-3-carboxylate (3c):



White solid; 93% yield (65.5 mg); mp = 93.5-94.6 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.51 (d, J = 8.3 Hz, 1H), 8.21 (dd, J = 8.3, 1.8 Hz, 1H), 7.87 (d, J = 1.7 Hz, 1H), 7.46-7.36 (m, 1H), 7.32 (t, J = 7.5 Hz, 1H), 7.24-7.15 (m, 6H), 7.00-6.92 (m, 2H), 3.92 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ

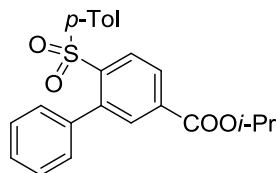
165.52, 143.54, 142.48, 140.24, 137.23, 134.05, 133.68, 132.83, 129.96, 128.82, 128.58, 128.44, 127.97, 127.81, 127.46, 52.62; **HRMS** (ESI) calcd for $C_{20}H_{17}O_4S$ ($M+H$)⁺: 353.0842, found: 353.0854; **IR** (KBr): ν = 3050, 2958, 2921, 2851, 1723, 1314, 1246, 1154, 1091, 737, 606, 555 cm^{-1} .

Ethyl 6-tosyl-[1,1'-biphenyl]-3-carboxylate (3d):



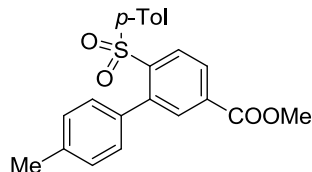
White viscous solid; 92% yield (70.0 mg); **¹H NMR** (400 MHz, $CDCl_3$) δ 8.48 (d, J = 8.3 Hz, 1H), 8.20 (dd, J = 8.3, 1.7 Hz, 1H), 7.86 (d, J = 1.6 Hz, 1H), 7.33 (t, J = 7.5 Hz, 1H), 7.22 (t, J = 7.7 Hz, 2H), 7.10 (d, J = 8.3 Hz, 2H), 6.99 (m, 4H), 4.38 (q, J = 7.1 Hz, 2H), 2.32 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H); **¹³C NMR** (101 MHz, $CDCl_3$) δ 165.07, 143.81, 143.75, 142.34, 137.46, 137.39, 134.26, 133.57, 129.99, 129.06, 128.72, 128.54, 127.93, 127.89, 127.37, 61.68, 21.50, 14.24; **HRMS** (ESI) calcd for $C_{22}H_{21}O_4S$ ($M+H$)⁺: 381.1155, found: 381.1172; **IR** (KBr): ν = 3030, 2961, 2923, 2853, 1721, 1303, 1237, 1155, 1091, 764, 660, 544 cm^{-1} .

Isopropyl 6-tosyl-[1,1'-biphenyl]-3-carboxylate (3e):



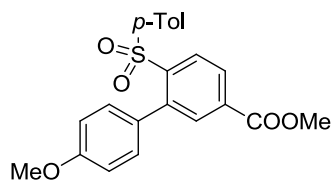
White solid; 95% yield (75.0 mg); mp = 133.6-134.7 °C; **¹H NMR** (400 MHz, $CDCl_3$) δ 8.48 (d, J = 8.3 Hz, 1H), 8.19 (dd, J = 8.3, 1.6 Hz, 1H), 7.85 (d, J = 1.6 Hz, 1H), 7.33 (t, J = 7.4 Hz, 1H), 7.22 (t, J = 7.7 Hz, 2H), 7.10 (d, J = 8.2 Hz, 2H), 7.02-6.95 (m, 4H), 5.33-5.19 (m, 1H), 2.32 (s, 3H), 1.35 (d, J = 6.3 Hz, 6H); **¹³C NMR** (101 MHz, $CDCl_3$) δ 164.56, 143.80, 143.65, 142.29, 137.51, 137.42, 134.69, 133.50, 130.02, 129.06, 128.69, 128.53, 127.92, 127.88, 127.36, 69.37, 21.84, 21.50; **HRMS** (ESI) calcd for $C_{23}H_{23}O_4S$ ($M+H$)⁺: 395.1312, found: 395.1327; **IR** (KBr): ν = 3035, 2979, 2922, 2856, 1715, 1300, 1247, 1150, 1089, 768, 661, 598 cm^{-1} .

Methyl 4'-methyl-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3f):



White solid; 98% yield (74.6 mg); mp = 120.6-121.9 °C; **¹H NMR** (400 MHz, $CDCl_3$) δ 8.44 (d, J = 8.3 Hz, 1H), 8.16 (dd, J = 8.3, 1.8 Hz, 1H), 7.85 (d, J = 1.7 Hz, 1H), 7.13 (d, J = 8.3 Hz, 2H), 7.01 (m, 4H), 6.88 (d, J = 8.0 Hz, 2H), 3.91 (s, 3H), 2.39 (s, 3H), 2.33 (s, 3H); **¹³C NMR** (101 MHz, $CDCl_3$) δ 165.60, 144.00, 143.83, 142.53, 137.80, 137.44, 134.56, 133.81, 129.83, 128.98, 128.75, 128.37, 128.02, 127.96, 52.56, 21.53, 21.26; **HRMS** (ESI) calcd for $C_{22}H_{21}O_4S$ ($M+H$)⁺: 381.1155, found: 381.1167; **IR** (KBr): ν = 3037, 2950, 2921, 2850, 1731, 1318, 1309, 1153, 1090, 754, 658, 543 cm^{-1} .

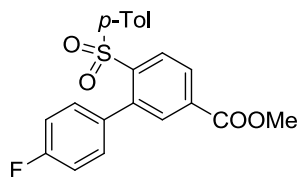
Methyl 4'-methoxy-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3g):



White viscous solid; 98% yield (77.7 mg); **¹H NMR** (400 MHz, $CDCl_3$) δ 8.45 (d, J = 8.3 Hz, 1H), 8.16 (dd, J = 8.3, 1.8 Hz, 1H), 7.85 (d, J = 1.7 Hz, 1H), 7.13 (d, J = 8.3 Hz, 2H), 7.01 (d, J = 8.1 Hz, 2H), 6.92 (d, J = 8.8 Hz, 2H), 6.76 (d, J = 8.8 Hz, 2H), 3.91 (s, 3H), 3.85 (s, 3H), 2.33 (s, 3H); **¹³C NMR** (101 MHz, $CDCl_3$) δ 165.61, 159.56, 144.12, 143.79, 142.26, 137.41, 133.98, 133.84, 131.22, 129.72, 129.01, 128.77, 128.30, 127.87, 112.86, 55.37, 52.56, 21.51; **HRMS** (ESI) calcd for $C_{22}H_{21}O_5S$ ($M+H$)⁺: 397.1104,

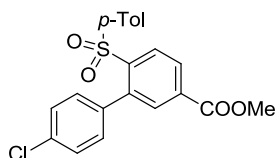
found: 397.1122; **IR** (KBr): ν = 3067, 2955, 2923, 2851, 1727, 1515, 1304, 1248, 1154, 1091, 736, 660 cm^{-1} .

Methyl 4'-fluoro-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3h):



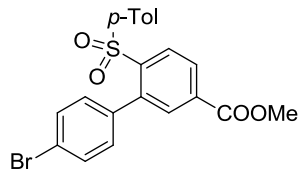
White solid; 96% yield (73.8 mg); mp = 89.4-91.2 $^{\circ}\text{C}$; **^1H NMR** (400 MHz, CDCl_3) δ 8.47 (d, J = 8.3 Hz, 1H), 8.20 (dd, J = 8.3, 1.7 Hz, 1H), 7.84 (d, J = 1.7 Hz, 1H), 7.14 (d, J = 8.3 Hz, 2H), 7.05 (d, J = 8.2 Hz, 2H), 7.00-6.88 (m, 4H), 3.93 (s, 3H), 2.34 (s, 3H); **^{13}C NMR** (101 MHz, CDCl_3) δ 165.44, 162.66 (d, J = 247.9 Hz), 144.10, 144.00, 141.30, 137.31, 133.99, 133.70, 133.30 (d, J = 3.3 Hz), 131.81 (d, J = 8.4 Hz), 129.15, 128.84 (d, J = 9.0 Hz), 127.79, 114.45, 114.23, 52.64, 21.52; **HRMS** (ESI) calcd for $\text{C}_{21}\text{H}_{18}\text{O}_4\text{SF}$ ($\text{M}+\text{H}^+$): 385.0904, found: 385.0906; **IR** (KBr): ν = 3070, 2957, 2922, 2851, 1725, 1511, 1315, 1223, 1153, 1091, 660, 543 cm^{-1} .

Methyl 4'-chloro-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3i):



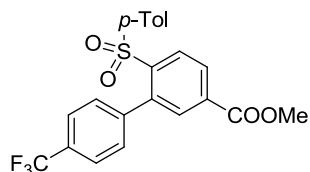
White solid; 97% yield (77.8 mg); mp = 122.5-126.4 $^{\circ}\text{C}$; **^1H NMR** (400 MHz, CDCl_3) δ 8.37 (d, J = 8.3 Hz, 1H), 8.11 (dd, J = 8.3, 1.7 Hz, 1H), 7.75 (d, J = 1.6 Hz, 1H), 7.11 (d, J = 8.4 Hz, 2H), 7.07 (d, J = 8.3 Hz, 2H), 6.97 (d, J = 8.2 Hz, 2H), 6.84 (d, J = 8.4 Hz, 2H), 3.84 (s, 3H), 2.27 (s, 3H); **^{13}C NMR** (101 MHz, CDCl_3) δ 164.37, 143.18, 142.95, 140.01, 136.24, 134.79, 133.31, 133.00, 132.43, 130.31, 128.16, 127.91, 127.88, 126.84, 126.53, 51.64, 20.53; **HRMS** (ESI) calcd for $\text{C}_{21}\text{H}_{18}\text{O}_4\text{SCl}$ ($\text{M}+\text{H}^+$): 401.0609, found: 401.0626; **IR** (KBr): ν = 3070, 2955, 2921, 2850, 1728, 1306, 1249, 1154, 1090, 723, 666, 543 cm^{-1} .

Methyl 4'-bromo-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3j):

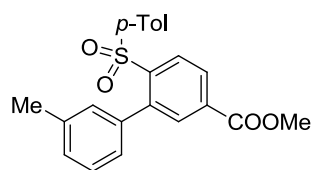


White solid; 97% yield (86.4 mg); mp = 144.5-146.4 $^{\circ}\text{C}$; **^1H NMR** (400 MHz, CDCl_3) δ 8.47 (d, J = 8.3 Hz, 1H), 8.21 (dd, J = 8.3, 1.7 Hz, 1H), 7.84 (d, J = 1.7 Hz, 1H), 7.42-7.30 (m, 2H), 7.17 (d, J = 8.3 Hz, 2H), 7.07 (d, J = 8.1 Hz, 2H), 6.88 (d, J = 8.4 Hz, 2H), 3.94 (s, 3H), 2.37 (s, 3H); **^{13}C NMR** (101 MHz, CDCl_3) δ 165.37, 144.21, 143.92, 140.98, 137.22, 136.28, 134.02, 133.34, 131.61, 130.52, 129.19, 128.95, 128.88, 127.86, 122.50, 52.67, 21.56; **HRMS** (ESI) calcd for $\text{C}_{21}\text{H}_{18}\text{O}_4\text{SBr}$ ($\text{M}+\text{H}^+$): 445.0104, found: 445.0114; **IR** (KBr): ν = 3123, 2957, 2921, 2851, 1728, 1306, 1155, 1091, 1012, 813, 660, 543 cm^{-1} .

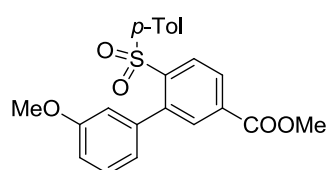
Methyl 6-tosyl-4'-(trifluoromethyl)-[1,1'-biphenyl]-3-carboxylate (3k):



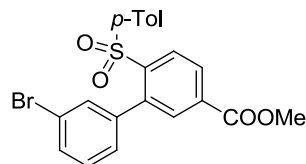
White solid; 99% yield (86.0 mg); mp = 159.3-160.2 $^{\circ}\text{C}$; **^1H NMR** (400 MHz, CDCl_3) δ 8.49 (d, J = 8.3 Hz, 1H), 8.24 (dd, J = 8.3, 1.7 Hz, 1H), 7.85 (d, J = 1.7 Hz, 1H), 7.47 (d, J = 8.1 Hz, 2H), 7.11 (m, 4H), 7.01 (d, J = 8.1 Hz, 2H), 3.94 (s, 3H), 2.34 (s, 3H); **^{13}C NMR** (101 MHz, CDCl_3) δ 165.29, 144.26, 143.93, 141.00, 140.63, 137.07, 134.11, 133.11, 130.40, 129.23, 128.87, 127.79, 124.27 (q, J = 3.4 Hz), 52.69, 21.48; **HRMS** (ESI) calcd for $\text{C}_{22}\text{H}_{18}\text{O}_4\text{SF}_3$ ($\text{M}+\text{H}^+$): 435.0872, found: 435.0892; **IR** (KBr): ν = 3085, 2959, 2923, 2853, 1736, 1319, 1157, 1106, 1093, 709, 660, 541 cm^{-1} .

Methyl 3'-methyl-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3l):

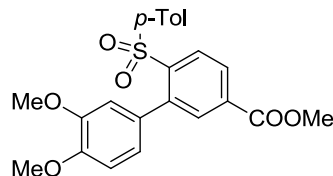
White solid; 98% yield (74.6 mg); mp = 125.3-127.1 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.47 (d, J = 8.3 Hz, 1H), 8.18 (dd, J = 8.3, 1.8 Hz, 1H), 7.85 (d, J = 1.6 Hz, 1H), 7.12 (m, 4H), 7.00 (d, J = 8.1 Hz, 2H), 6.89 (d, J = 6.2 Hz, 1H), 6.58 (s, 1H), 3.91 (s, 3H), 2.33 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.58, 143.90, 143.69, 142.54, 137.43, 137.24, 136.94, 133.81, 133.53, 130.28, 128.97, 128.61, 128.57, 128.44, 127.97, 127.30, 127.24, 52.57, 21.46, 21.16; **HRMS** (ESI) calcd for $\text{C}_{22}\text{H}_{21}\text{O}_4\text{S}$ ($\text{M}+\text{H}$) $^+$: 381.1155, found: 381.1167; **IR** (KBr): ν = 3035, 2957, 2922, 2851, 1730, 1316, 1256, 1153, 1093, 753, 660, 542 cm^{-1} .

Methyl 3'-methoxy-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3m):

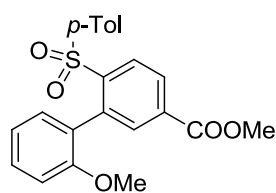
White solid; 97% yield (76.9 mg); mp = 133.3-134.4 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.48 (d, J = 8.3 Hz, 1H), 8.19 (dd, J = 8.3, 1.8 Hz, 1H), 7.87 (d, J = 1.7 Hz, 1H), 7.14 (m, 3H), 7.01 (d, J = 8.1 Hz, 2H), 6.87 (dd, J = 7.9, 2.8 Hz, 1H), 6.62 (d, J = 7.6 Hz, 1H), 6.45-6.33 (m, 1H), 3.92 (s, 3H), 3.68 (s, 3H), 2.33 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.54, 158.64, 143.94, 143.79, 142.11, 138.44, 137.31, 133.85, 133.41, 129.03, 128.61, 128.59, 128.42, 127.97, 122.60, 114.83, 114.31, 55.02, 52.59, 21.45; **HRMS** (ESI) calcd for $\text{C}_{22}\text{H}_{21}\text{O}_5\text{S}$ ($\text{M}+\text{H}$) $^+$: 397.1104, found: 397.1121; **IR** (KBr): ν = 3015, 2952, 2921, 2851, 1727, 1320, 1259, 1157, 1096, 738, 659, 591 cm^{-1} .

Methyl 3'-bromo-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3n):

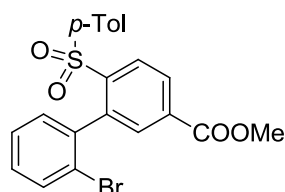
White solid; 95% yield (84.6 mg); mp = 147.8-150.4 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.49 (d, J = 8.3 Hz, 1H), 8.22 (dd, J = 8.3, 1.7 Hz, 1H), 7.83 (d, J = 1.6 Hz, 1H), 7.45 (dt, J = 7.5, 1.8 Hz, 1H), 7.18 (m, 2H), 7.13 (d, J = 8.5 Hz, 2H), 7.07 (d, J = 8.2 Hz, 2H), 6.76 (d, J = 1.6 Hz, 1H), 3.93 (s, 3H), 2.38 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.33, 144.37, 143.93, 140.54, 139.19, 137.06, 134.02, 133.20, 132.17, 130.94, 130.86, 129.33, 129.10, 129.96, 128.73, 127.79, 121.52, 52.68, 21.61; **HRMS** (ESI) calcd for $\text{C}_{21}\text{H}_{18}\text{O}_4\text{SBr}$ ($\text{M}+\text{H}$) $^+$: 445.0104, found: 445.0112; **IR** (KBr): ν = 3066, 2954, 2921, 2851, 1729, 1308, 1234, 1154, 1090, 721, 658, 544 cm^{-1} .

Methyl 3',4'-dimethoxy-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3o):

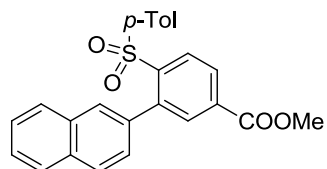
White solid; 99% yield (84.4 mg); mp = 160.1-162.3 °C; ^1H NMR (400 MHz, CDCl_3) δ 8.46 (d, J = 8.3 Hz, 1H), 8.16 (dd, J = 8.3, 1.7 Hz, 1H), 7.86 (d, J = 1.7 Hz, 1H), 7.12 (d, J = 8.3 Hz, 2H), 7.01 (d, J = 8.2 Hz, 2H), 6.75 (d, J = 8.3 Hz, 1H), 6.61 (m, 1H), 6.38 (d, J = 1.9 Hz, 1H), 3.92 (s, 3H), 3.91 (s, 3H), 3.67 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 165.57, 148.94, 147.86, 144.22, 143.70, 142.12, 137.38, 133.84, 133.72, 129.71, 128.93, 128.62, 128.36, 127.92, 122.82, 113.18, 110.19, 56.04, 55.51, 52.57, 21.43; **HRMS** (ESI) calcd for $\text{C}_{23}\text{H}_{23}\text{O}_6\text{S}$ ($\text{M}+\text{H}$) $^+$: 427.1210, found: 427.1226; **IR** (KBr): ν = 3073, 2957, 2921, 2850, 1718, 1316, 1242, 1153, 1090, 752, 659, 588 cm^{-1} .

Methyl 2'-methoxy-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3p):

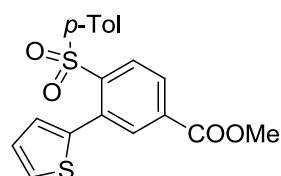
White solid; 91% yield (72.2 mg); mp = 133.1-134.7.4 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.48 (d, J = 8.3 Hz, 1H), 8.17 (dd, J = 8.3, 1.8 Hz, 1H), 7.84 (d, J = 1.7 Hz, 1H), 7.30 (m, 1H), 7.14 (d, J = 8.3 Hz, 2H), 7.08-6.99 (m, 3H), 6.91 (t, J = 7.1 Hz, 1H), 6.61 (d, J = 8.3 Hz, 1H), 3.90 (s, 3H), 3.28 (s, 3H), 2.34 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.72, 156.45, 144.18, 143.48, 138.85, 137.33, 134.36, 133.74, 132.14, 129.91, 128.85, 128.82, 128.55, 128.07, 125.72, 119.47, 109.86, 54.68, 52.50, 21.49; **HRMS** (ESI) calcd for $\text{C}_{22}\text{H}_{21}\text{O}_5\text{S}$ ($\text{M}+\text{H}$) $^+$: 397.1104, found: 397.1115; **IR** (KBr): ν = 3072, 2955, 2922, 2852, 1718, 1303, 1272, 1255, 1152, 1089, 759, 547 cm^{-1} .

Methyl 2'-bromo-6-tosyl-[1,1'-biphenyl]-3-carboxylate (3q):

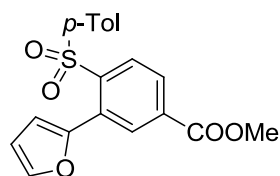
White solid; 89% yield (79.3 mg); mp = 114.7-115.9 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.49 (d, J = 8.3 Hz, 1H), 8.23 (dd, J = 8.3, 1.8 Hz, 1H), 7.86 (d, J = 1.7 Hz, 1H), 7.39 (d, J = 8.0 Hz, 1H), 7.36-7.30 (m, 1H), 7.29-7.22 (m, 2H), 7.17 (d, J = 8.3 Hz, 2H), 7.06 (d, J = 8.1 Hz, 2H), 3.92 (s, 3H), 2.36 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.41, 144.39, 143.45, 140.53, 137.48, 136.65, 134.10, 133.92, 132.87, 132.07, 129.92, 129.35, 128.93, 128.31, 126.34, 124.25, 52.64, 21.58; **HRMS** (ESI) calcd for $\text{C}_{21}\text{H}_{18}\text{O}_4\text{SBr}$ ($\text{M}+\text{H}$) $^+$: 445.0104, found: 445.0117; **IR** (KBr): ν = 3065, 2954, 2922, 2850, 1727, 1317, 1278, 1154, 1091, 755, 656, 542 cm^{-1} .

Methyl 3-(naphthalen-2-yl)-4-tosylbenzoate (3r):

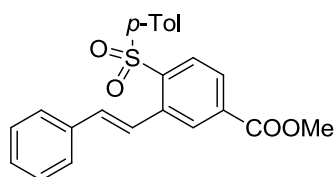
White solid; 94% yield (78.3 mg); mp = 137.3-139.1 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.52 (d, J = 8.3 Hz, 1H), 8.22 (dd, J = 8.3, 1.7 Hz, 1H), 7.94 (d, J = 1.7 Hz, 1H), 7.86 (d, J = 7.9 Hz, 1H), 7.72 (d, J = 8.4 Hz, 1H), 7.59 (d, J = 7.9 Hz, 1H), 7.55-7.44 (m, 2H), 7.25 (s, 1H), 7.20 (m, 1H), 7.00 (d, J = 8.3 Hz, 2H), 6.74 (d, J = 8.2 Hz, 2H), 3.91 (s, 3H), 2.20 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.57, 144.21, 143.85, 142.31, 137.29, 134.86, 133.91, 133.67, 132.64, 132.38, 129.04, 128.89, 128.72, 128.69, 128.04, 127.84, 127.74, 127.65, 126.88, 126.54, 126.27, 52.62, 21.37; **HRMS** (ESI) calcd for $\text{C}_{25}\text{H}_{21}\text{O}_4\text{S}$ ($\text{M}+\text{H}$) $^+$: 417.1155, found: 417.1172; **IR** (KBr): ν = 3060, 2959, 2921, 2851, 1731, 1303, 1153, 1089, 751, 658, 598, 541 cm^{-1} .

Methyl 3-(thiophen-2-yl)-4-tosylbenzoate (3s):

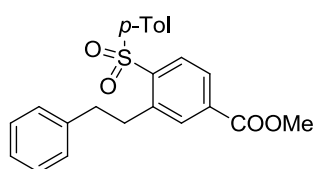
White solid; 95% yield (70.8 mg); mp = 98.3-100.9 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.50 (d, J = 8.3 Hz, 1H), 8.19 (dd, J = 8.3, 1.7 Hz, 1H), 7.99 (d, J = 1.7 Hz, 1H), 7.30 (dd, J = 5.1, 1.1 Hz, 1H), 7.22 (d, J = 8.3 Hz, 2H), 7.17 (dd, J = 3.5, 1.1 Hz, 1H), 7.05 (d, J = 8.1 Hz, 2H), 7.00 (dd, J = 5.1, 3.6 Hz, 1H), 3.93 (s, 3H), 2.33 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.31, 144.84, 143.95, 136.84, 136.72, 134.90, 134.78, 133.83, 131.17, 129.23, 129.13, 129.11, 127.84, 127.48, 126.69, 52.66, 21.55; **HRMS** (ESI) calcd for $\text{C}_{19}\text{H}_{17}\text{O}_4\text{S}_2$ ($\text{M}+\text{H}$) $^+$: 373.0563, found: 373.0569; **IR** (KBr): ν = 3104, 2956, 2921, 2852, 1723, 1281, 1153, 1090, 706, 659, 587, 534 cm^{-1} .

Methyl 3-(furan-2-yl)-4-tosylbenzoate (3t):

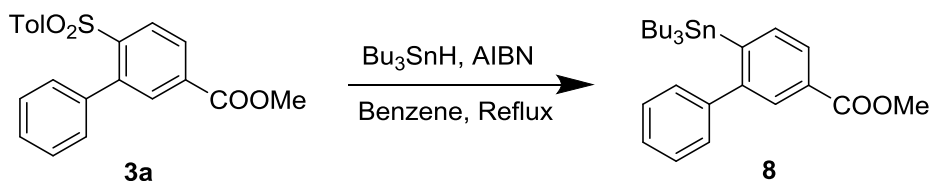
White solid; 98% yield (69.9 mg); mp = 81.7-82.1 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.38 (d, J = 8.3 Hz, 1H), 8.19 (d, J = 1.6 Hz, 1H), 8.13 (dd, J = 8.3, 1.8 Hz, 1H), 7.49 (d, J = 8.3 Hz, 2H), 7.40 (d, J = 1.1 Hz, 1H), 7.16 (d, J = 8.1 Hz, 2H), 6.90 (d, J = 3.4 Hz, 1H), 6.46 (dd, J = 3.4, 1.8 Hz, 1H), 3.94 (s, 3H), 2.35 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.30, 148.15, 144.23, 143.35, 142.63, 137.19, 134.06, 132.72, 131.07, 129.87, 129.29, 128.92, 127.86, 113.66, 111.54, 52.67, 21.54; **HRMS** (ESI) calcd for $\text{C}_{19}\text{H}_{17}\text{O}_5\text{S}$ ($\text{M}+\text{H}$) $^+$: 357.0791, found: 357.0781; **IR** (KBr): ν = 3103, 2957, 2921, 2851, 1730, 1298, 1154, 1089, 750, 658, 600, 552 cm^{-1} .

(E)-Methyl 3-styryl-4-tosylbenzoate (5):

White solid; 82% yield (64.4 mg); mp = 139.7-141.9 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.21 (d, J = 7.9 Hz, 2H), 7.96 (d, J = 8.4 Hz, 1H), 7.85 (d, J = 16.2 Hz, 1H), 7.65 (d, J = 8.2 Hz, 2H), 7.41 (d, J = 7.5 Hz, 2H), 7.31 (t, J = 7.5 Hz, 2H), 7.24 (t, J = 7.2 Hz, 1H), 7.10 (d, J = 8.2 Hz, 2H), 6.82 (d, J = 16.2 Hz, 1H), 3.87 (s, 3H), 2.23 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 165.66, 144.48, 141.79, 138.00, 137.86, 136.43, 134.60, 134.38, 129.69, 129.47, 129.10, 128.82, 128.65, 128.12, 127.82, 127.08, 123.71, 52.67, 21.52; **HRMS** (ESI) calcd for $\text{C}_{23}\text{H}_{21}\text{O}_4\text{S}$ ($\text{M}+\text{H}$) $^+$: 393.1155, found: 393.1166; **IR** (KBr): ν = 3065, 3030, 2957, 2921, 2851, 1721, 1287, 1154, 1087, 758, 658, 598 cm^{-1} .

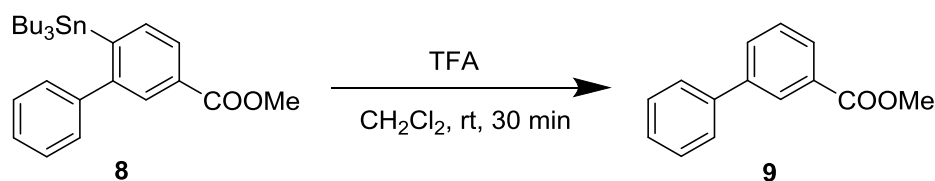
Methyl 3-phenethyl-4-tosylbenzoate (7):

White solid; 96% yield (75.7 mg); mp = 111.7-112.9 °C; $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 8.16 (d, J = 8.3 Hz, 1H), 7.93 (dd, J = 8.3, 1.7 Hz, 1H), 7.85 (d, J = 1.5 Hz, 1H), 7.66 (d, J = 8.3 Hz, 2H), 7.27-7.16 (m, 4H), 7.11 (m, 3H), 3.84 (s, 3H), 3.15-3.02 (m, 2H), 2.80-2.63 (m, 2H), 2.31 (s, 3H); $^{13}\text{C NMR}$ (101 MHz, CDCl_3) δ 164.66, 143.46, 142.11, 141.00, 140.03, 137.30, 133.39, 132.01, 128.91, 128.81, 127.43, 126.63, 126.47, 125.14, 51.55, 36.49, 34.03, 20.55; **HRMS** (ESI) calcd for $\text{C}_{23}\text{H}_{23}\text{O}_4\text{S}$ ($\text{M}+\text{H}$) $^+$: 395.1312, found: 395.1324; **IR** (KBr): ν = 3062, 2962, 2921, 2851, 1715, 1294, 1154, 1087, 754, 655, 596, 538 cm^{-1} .

IV. Typical procedure for the synthesis of products 8-11**(1) Synthesis of methyl 6-(tributylstannyl)-[1,1'-biphenyl]-3-carboxylate (8)^[5]**

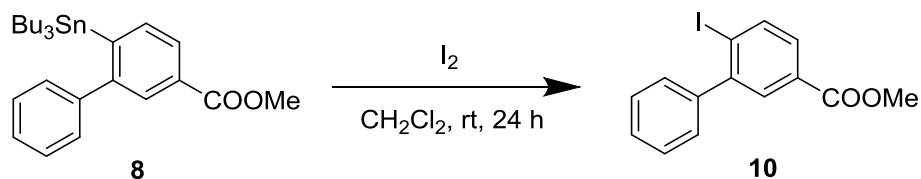
A mixture containing of arylsulfone **3a** (100 mg, 0.27 mmol), Bu₃SnH (290 mg, 1 mmol) and AIBN (50 mg, 0.3 mmol) in benzene (20 mL) under argon atmosphere was heated at reflux for 24 h. The mixture was cooled, poured into an aqueous KF solution and the aqueous layer was extracted with ether. After drying over Na₂SO₄, the solvent was removed under reduced pressure and the crude product was purified by thin layer chromatography (petroleum ether/ethyl acetate =20:1) to give **8** (97.5 mg, 72%) as a colourless oil; ¹H NMR (400 MHz, CDCl₃) δ 7.98 (d, *J* = 1.5 Hz, 1H), 7.94 (dd, *J* = 7.6, 1.7 Hz, 1H), 7.62 (d, *J* = 7.6 Hz, 1H), 7.38 (m, 3H), 7.31 (m, 2H), 3.91 (s, 3H), 1.36-1.30 (m, 6H), 1.25-1.20 (m, 6H), 0.83 (t, *J* = 7.2 Hz, 9H), 0.77-0.72 (m, 6H); ¹³C NMR (101 MHz, CDCl₃) δ 167.42, 150.63, 149.41, 144.85, 137.08, 129.74, 129.10, 128.76, 128.30, 127.38, 126.72, 52.02, 28.96, 27.26, 13.59, 10.88.

(2) Synthesis of methyl [1,1'-biphenyl]-3-carboxylate (**9**)



To a solution of organostannane **8** (150.4 mg, 0.3 mmol) in CH₂Cl₂ (10 mL) was added TFA (2 mL) at room temperature. After stirring for 30 min, the reaction mixture was poured into an aqueous KF solution and the aqueous layer was extracted with diethyl ether. The organic layers were washed with brine, dried, and evaporated under reduced pressure. The crude product was purified by flash column chromatography (petroleum ether/ethyl acetate = 20:1) to give biaryl compound **9** (61.1 mg, 96%) as a colourless oil; ¹H NMR (400 MHz, CDCl₃) δ 8.18 (s, 1H), 7.91 (d, *J* = 7.8 Hz, 1H), 7.66 (d, *J* = 7.8 Hz, 1H), 7.51 (d, *J* = 7.3 Hz, 2H), 7.40-7.31 (m, 3H), 7.26 (t, *J* = 7.3 Hz, 1H), 3.83 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 165.98, 140.43, 139.07, 130.45, 129.68, 127.84, 127.79, 127.30, 127.21, 126.69, 126.10, 51.10; HRMS (ESI) calcd for C₁₄H₁₃O₂ (M+H)⁺: 213.0910, found: 213.0906; IR (KBr): ν = 3032, 2953, 2920, 2850, 1720, 1435, 1300, 1241, 1110, 1086, 741, 696 cm⁻¹.

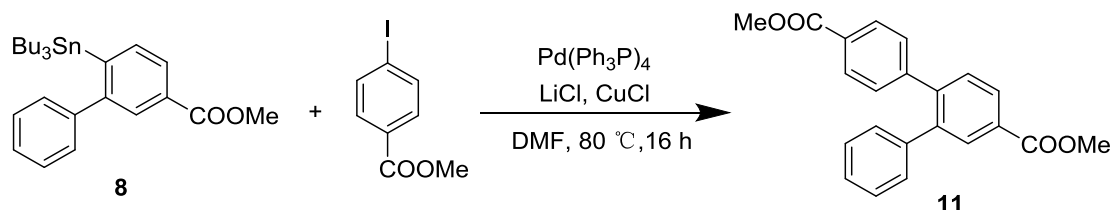
(3) Synthesis of methyl 6-iodo-[1,1'-biphenyl]-3-carboxylate (**10**)^[6]



To a solution of organostannane **8** (150.4 mg, 0.3 mmol) in CH₂Cl₂ (5 mL) was added a solution of iodine (101.5 mg, 0.4 mmol) in CH₂Cl₂ (10 mL) at room temperature, then the mixture was stirred for 24 h. After the starting material was consumed, the reaction mixture was quenched with saturated Na₂S₂O₃ solution, washed with KF aqueous solution, extracted with ether. The extraction was washed with brine, dried, and evaporated under reduced pressure. The crude product was purified by flash column chromatography (petroleum ether/ethyl acetate = 20:1) to afford iodinated product **10** (88.3 mg, 87%) as a white solid; mp = 78.0-81.8°C; ¹H NMR (400 MHz, CDCl₃) δ 7.96 (d, *J* = 8.2 Hz, 1H), 7.86 (d, *J* = 2.1 Hz, 1H), 7.58 (dd, *J* = 8.2, 2.1 Hz, 1H), 7.39-7.30 (m, 3H), 7.25 (dd, *J* = 7.6, 1.8 Hz, 2H), 3.82 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ

165.50, 146.01, 142.32, 138.79, 129.62, 129.22, 128.30, 128.15, 127.07, 126.99, 103.88, 51.26;
IR (KBr): ν = 3057, 2952, 2922, 2852, 1716, 1434, 1307, 1235, 1104, 1010, 754, 704 cm^{-1} .

(3) Synthesis of Dimethyl [1,1':2',1''-terphenyl]-4,4'-dicarboxylate (**11**)^[6]

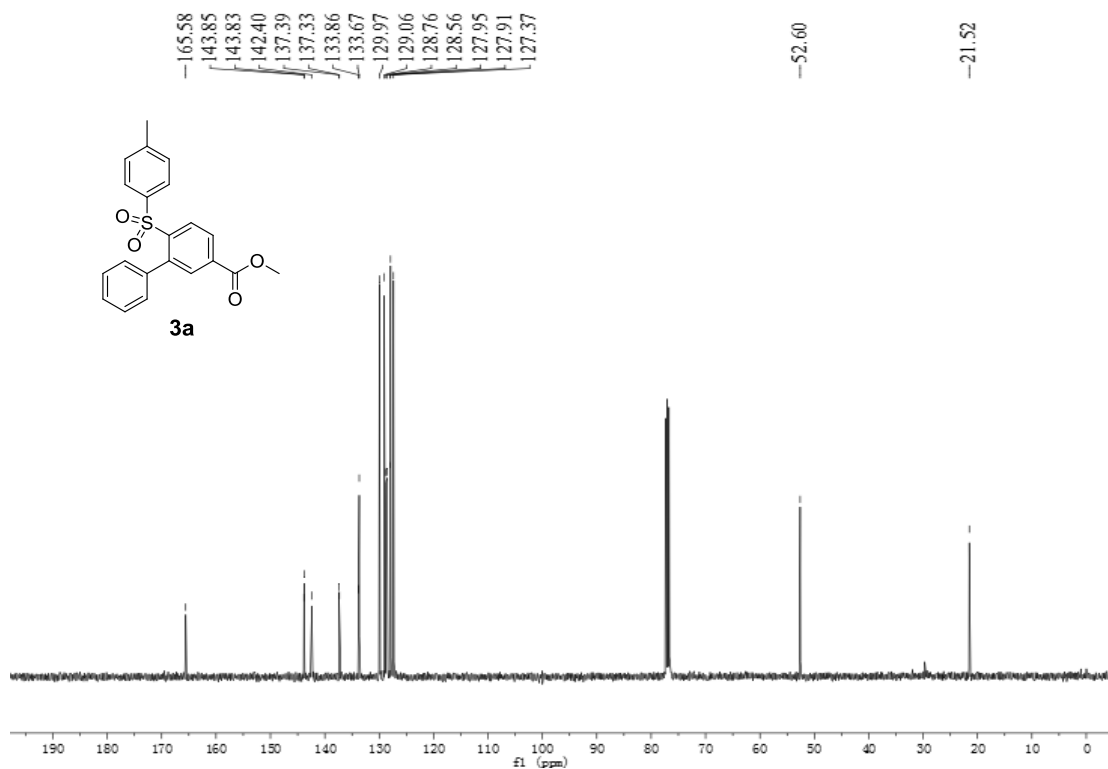
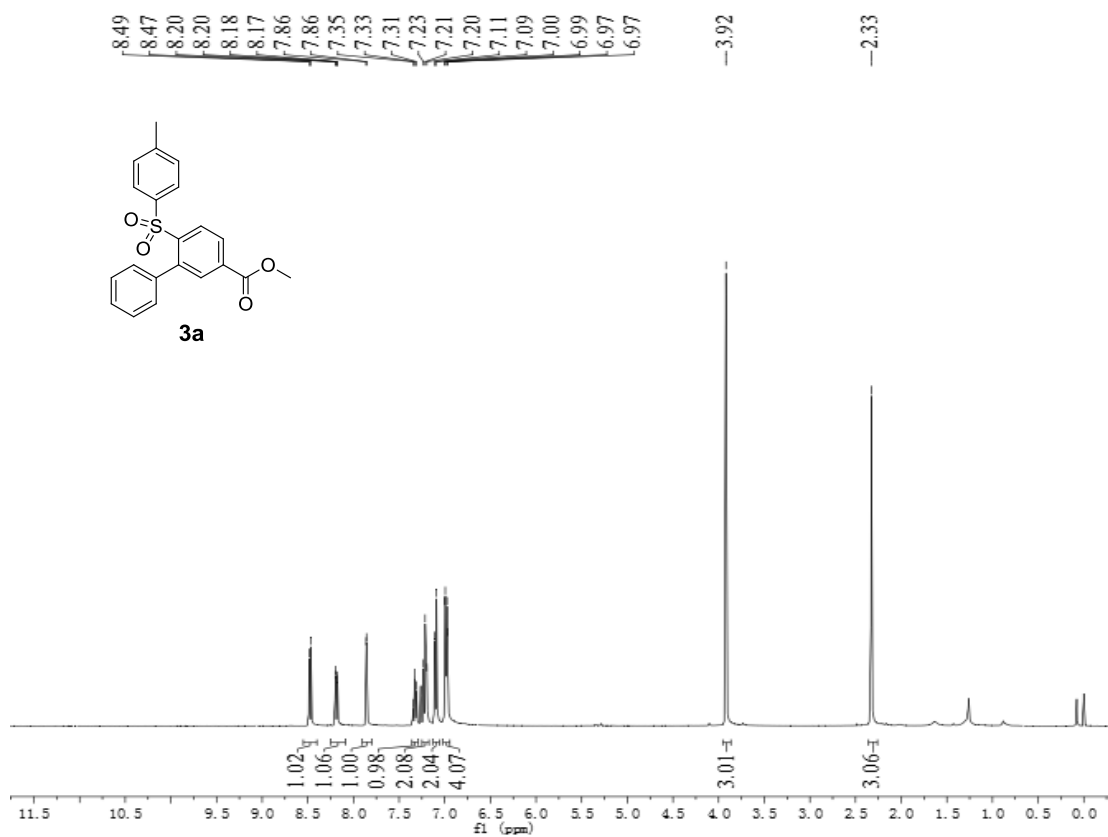


To a solution of LiCl (50.9 mg, 1.2 mmol), CuCl (118.8 mg, 1.2 mmol), Pd(PPh₃)₄ (69.3 mg, 0.06 mmol) and methyl 4-iodobenzoate (157.2 mg, 0.6 mmol) in DMF (4 mL) were added a solution of organostannane **8** (150.4 mg, 0.3 mmol) in DMF (2 mL) under argon at room temperature. The resulting dark red mixture was stirred at 80 °C for 16 h, diluted with diethyl ether (60 mL) and the organic layer was washed with KF aqueous solution and brine, dried over Na₂SO₄ and the solvent was removed under reduced pressure. The crude product was purified by column chromatography (petroleum ether/ethyl acetate = 10:1) to afford the product **11** (81.0 mg, 78%) as a white solid; mp = 137.7-140.8 °C; ¹H NMR (400 MHz, CDCl₃) δ 8.05 (d, J = 1.6 Hz, 1H), 8.00 (dd, J = 8.0, 1.8 Hz, 1H), 7.82 (d, J = 8.5 Hz, 2H), 7.42 (d, J = 8.0 Hz, 1H), 7.17-7.10 (m, 5H), 7.07-7.01 (m, 2H), 3.87 (s, 3H), 3.81 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 165.83, 165.70, 144.31, 142.87, 139.91, 139.08, 130.88, 129.54, 128.82, 128.74, 128.71, 128.29, 127.78, 127.55, 127.16, 126.13, 51.21, 51.06; **HRMS** (ESI) calcd for C₂₂H₁₈O₄Na (M+Na)⁺: 369.1097, found: 369.1098; **IR** (KBr): ν = 3057, 2957, 2921, 2851, 1716, 1434, 1306, 1281, 1235, 1100, 762, 698 cm^{-1} .

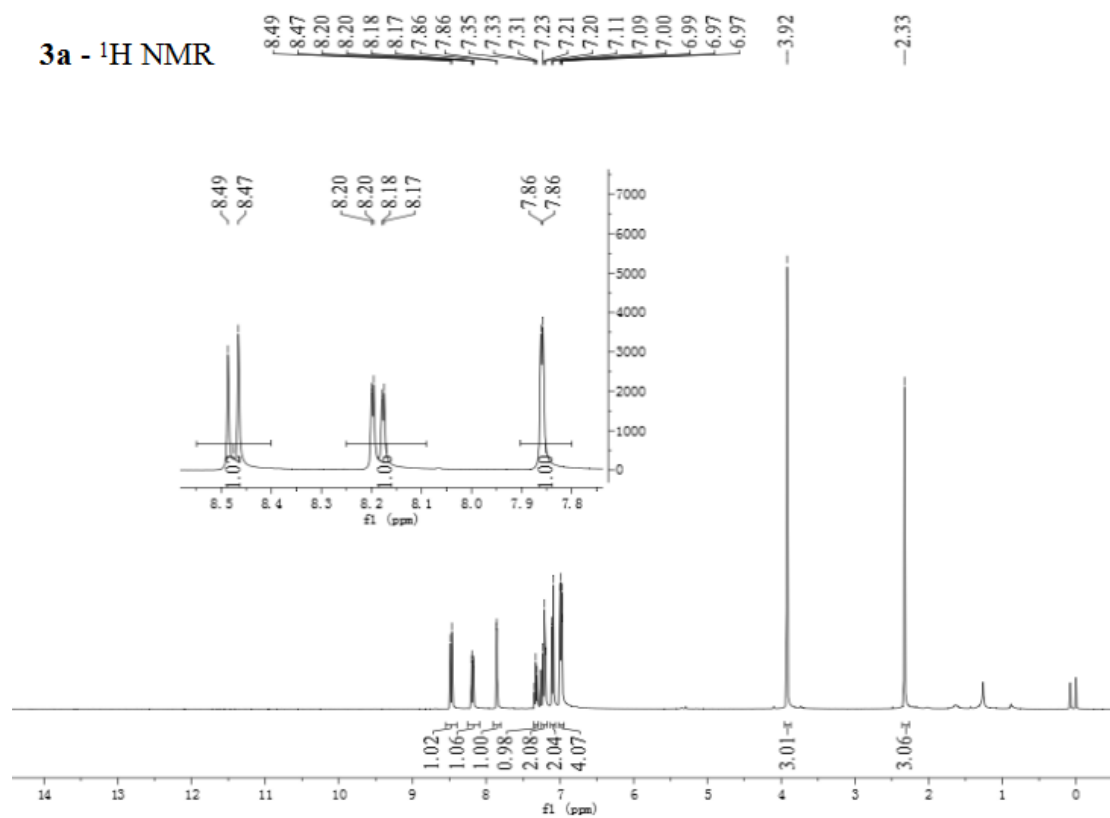
V. References

1. Du, Y. L.; Yu, A. M.; Jia, J. R.; Zhang, Y. Q.; Meng, X. T. *Chem. Commun.* **2017**, 53, 1684.
2. Hua, Y.-Z.; Liu, M.-M.; Huang, P.-J.; Song, X.-X.; Wang, M.-C.; Chang, J.-B. *Chem. Eur. J.* **2015**, 21, 11994.
3. Gremaud, L.; Alexakis, A. *Angew. Chem. Int. Ed.* **2012**, 51, 794.
4. Nođ, R.; Gembus, V.; Levacher, V.; Brière, J.-F. *Org. Biomol. Chem.* **2014**, 12, 1245.
5. Padwa, A.; Muller, C. L.; Rodriguez, A.; Watterson, S. H. *Tetrahedron* **1998**, 54, 9651.
6. Chen, Y. F.; Chen, M.; Liu, Y. H. *Angew. Chem. Int. Ed.* **2012**, 51, 6181.

VI. Copies of NMR spectra



3a - ^1H NMR



3a - HMBC

