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One-pot Wittig olefination–Suzuki reaction—the compatibility of conjugated phosphoranes in Pd(0) catalysed C–C-bond forming reactions

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Formylareneboronic acids and formylhetareneboronic acids can be subjected to a combined Suzuki coupling–Wittig olefination in their reaction with arene halides and conjugated phosphoranes. Also, the transformations can be carried out under ultrasonication in a biphasic medium of aq. Na_2CO_3 and hexane–ether, where phosphonium salts are used as the starting materials.

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Introduction

In the search for less time consuming processes and for processes with less consumption of solvents both for the reactions themselves and their work-up, multi-component one-pot transformations merit consideration. Within this field, stabilized phosphoranes offer interesting possibilities. π-Conjugated phosphoranes such as **3** are stable towards oxygen and moisture. Their reactivity towards carbonyl groups varies with the character of the π-system in conjugation with the P=C functionality.[1] While aroylmethylidenephosphoranes such as **3b** react with carbaldehydes but not with ketones, **3a** reacts with both aldehydes and ketones in solution,[1] but discriminates between the two in favor of the aldehydes in solventless reactions.[2] The authors have shown the possibility of carrying out C–C-bond forming reactions with haloaroylmethylidenephosphoranes for the construction of libraries of aryl/hetarylaroylmethylidenephosphoranes.[3] The stability of the π-conjugated phosphoranes, while still reactive towards carbonyl groups, in a number of different reaction conditions provides the opportunity to combine the Wittig olefination reaction with a second transformation in a one-pot procedure. Such combinations have been forwarded previously, where in the past the authors have described combinations of Wittig reactions with [4 + 2]-cycloaddition reactions.[4] In the following, the focus will be on methods of combining Suzuki-type C–C-bond forming syntheses with Wittig reactions.

Results and discussion

When mixtures of aryl/hetaryl halides, formylaryl/hetarylboronic acids and ethoxycarbonylmethylidenephosphorane (**3a**) were reacted under Pd(0) catalysis in a biphasic solution of 1,2-dimethoxyethane and 2 M aq. Na_2CO_3, ethyl bisaryl/hetarylacrylates **4** were obtained in good yield. A variety of commercially available formylarylboronic acids and formylthienylboronic acids could be used in the reactions (Scheme 1). In all cases, the *E*-configurated acrylates are the major isomer as can be expected for a Wittig olefination with a stabilized phosphorane.[1] Here, the *E* : *Z*-isomer ratios are >90%, except for the products **4i**, **4k** and **4L**, where the methoxy substituent, neighboring the formyl group, has a directing effect and the *E* : *Z* ratio is smaller.

The phosphorane component can be varied. Thus, not only the more reactive ester substituted methylidenephosphoranes **3a** and **3e** react well, but also the usually much less reactive α-ketomethylidentriphenylphosphoranes, such as **3b–d** and **3f**. In these cases, often longer reaction times are necessary. For the most part, here only the *E*-isomers can be isolated (Scheme 2).

Phenylmaleimide derived phosphorane **3g** can be used in the reaction to form **4r**. The reactivity of **3g** is lower than that of the ester containing methylidenephosphoranes. Again, the isomer formed is the *E*-product (Scheme 2).

Also, cyanomethylidenetriphenylphosphorane (**3h**) can be used as the phosphorane component in the transformations. Thus, the reaction of **1b** and **2a** with **3h** gave **4u** in good yield. The *E* : *Z* ratio, however, was found to be almost 1 : 1. When **5b** was reacted with **3h** in benzene in the presence of benzoic acid, the *E*-isomer was formed (Scheme 3) almost exclusively. The same phenomenon could be observed for the reaction of 2-bromothiophene (**1a**) with **2a** and **3h**, where the one-pot reaction in DME–aq. Na_2CO_3 gave **4s** with an *E* : *Z* ratio of 63 : 37. A Wittig reaction with the preformed Suzuki coupling product **5a** in benzene in the presence of benzoic acid again gave predominantly the *E*-isomer of **4s**. That this is not a directing effect of the palladium itself could be shown by running the reaction of **5a** and **3h** in a solvent mixture of DME and 2 M aq. Na_2CO_3, where again **4s** was formed in an *E* : *Z* ratio of 1 : 0.9. The influence of the solvent on the *E* : *Z* ratio of the olefins formed in certain Wittig reactions has been reported before.[1] In the combined, one-pot reaction, DME can in fact be exchanged for benzene, where the product forms in slightly lower yield, however, in an *E* : *Z* ratio of 10 : 1. Under these conditions a higher catalyst loading is used. **4s** can be hydrolysed easily to the acrylamide **4t** (Scheme 3).

The dependence of the *E* : *Z* ratio on the solvent system in these reactions is not limited to phosphorane **3h**. The reaction

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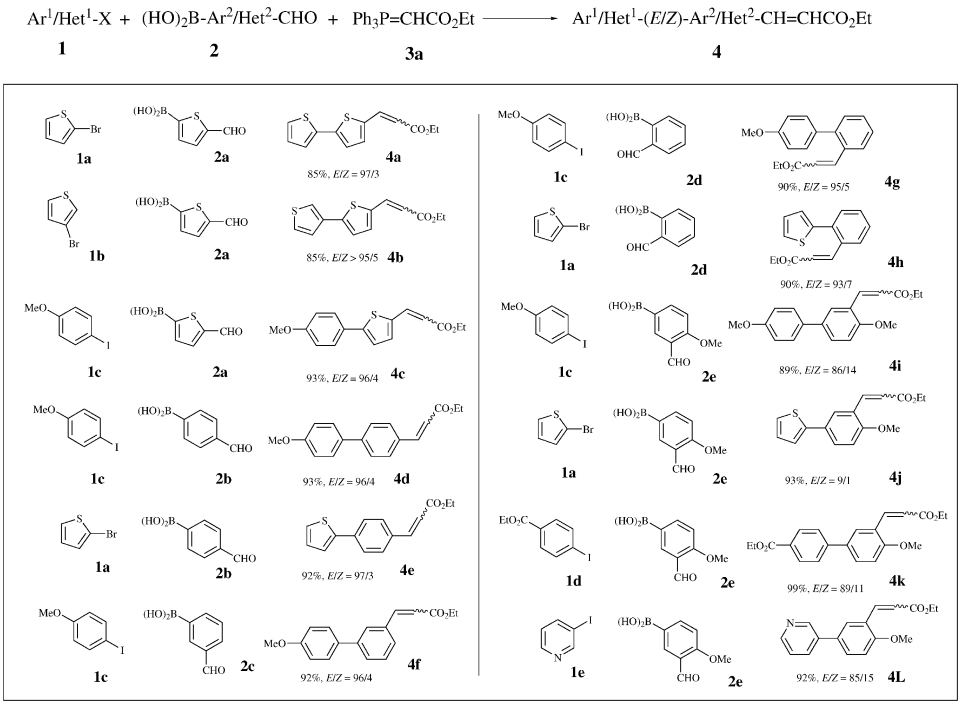
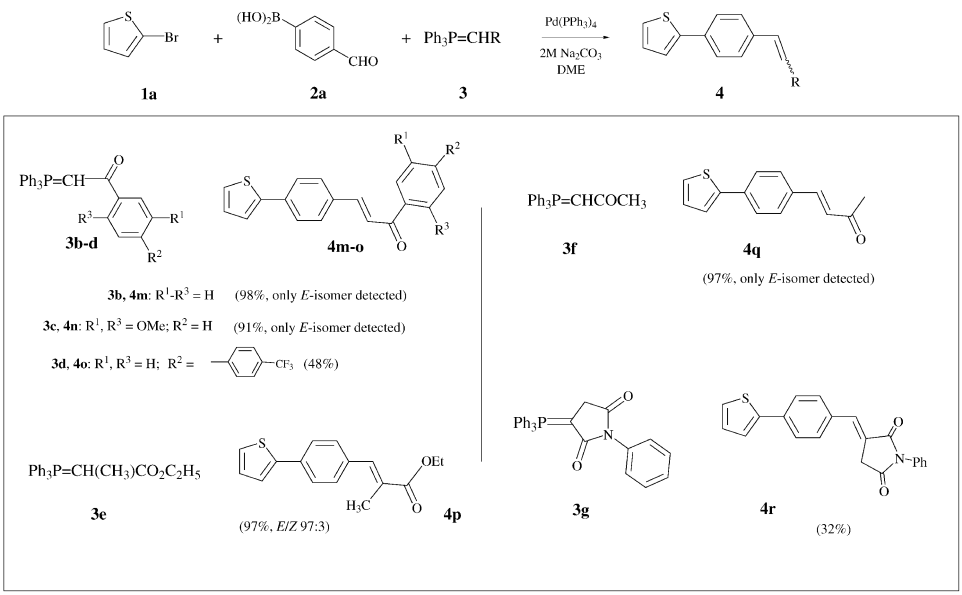


Scheme 1 One-pot Wittig olefination–Suzuki coupling reaction—variation of the boronic acid and aldehyde components.

of 3-iodopyridine (**1e**) in DME–aq. Na_2CO_3 gives *Z*-**4L** as the major product (*E* : *Z*, 12 : 88) (Scheme 4). Here again, a change to benzene in presence of benzoic acid[5] reverses the *cis* : *trans*-specificity of this transformation, where the reaction of **5c** and **3a** gives predominantly *E*-**4L** (Scheme 4).

3-Bromobenzo[*b*]thiophene (**6**) also undergoes the above transformation to give 3-substituted benzo[*b*]thiophenes **7** as coupling products (Scheme 5). No coupling at the 2-position or subsequent migration of the substituent to the 2-position, as reported[6] for Suzuki coupling reactions of **6** under other reaction conditions, could be observed. To unambiguously identify the regiochemistry of this reaction, coupling product **7a** was subjected to hydrogenation over Pd/C to form **8** and to subsequent hydrodesulfurization of **8** with Raney nickel to give exclusively the fully reduced compound **9** (Scheme 6).

Wittig reactions of carbaldehydes with **10a** and similar phosphonium salts and phosphoranes in a two phase system using ultrasonication had been carried out successfully by the authors.[7] A screening of the Suzuki coupling reactions with a limited number of iodoarenes, such as with 1-iodonaphthalene and phenylboronic acid to 1-phenylnaphthalene (hexane–ether 95 : 5 v/v; 2 M aq. Na_2CO_3, 98%) quickly showed that cross-



Scheme 2 One-pot Wittig olefination–Suzuki coupling reaction—variation of the phosphorane component.

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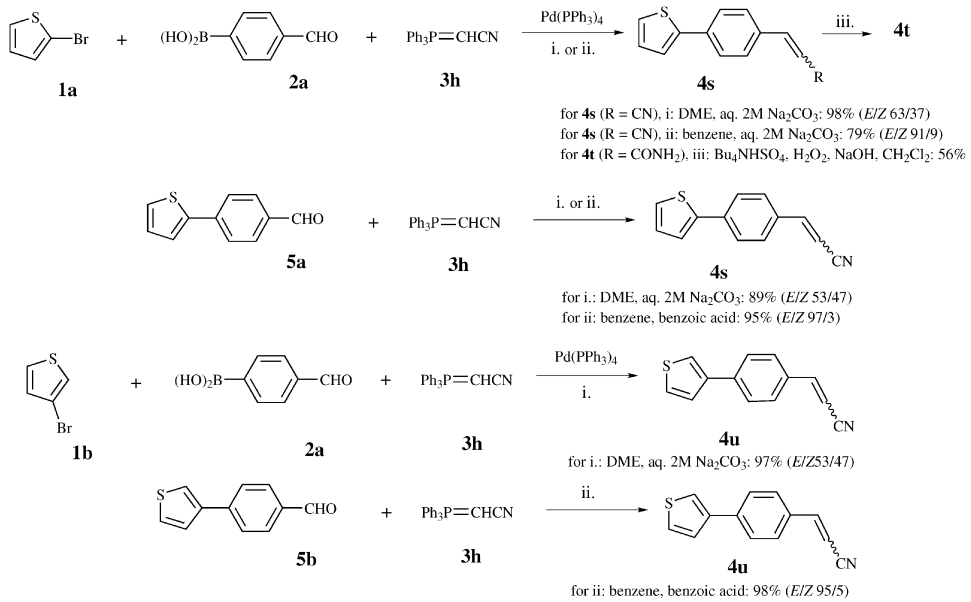


Scheme 3 Wittig reaction with cyanomethylidenetriphenylphosphorane—*E* : *Z*-isomeric dependence on reaction conditions.

coupling reactions also proceed successfully under conditions where ultrasound is used.[8–10] This led to the idea of combining the two processes as described above, albeit under ultrasonication. The use of ultrasound allows for the reaction to be carried out in a mixture of aq. 1 M Na_2CO_3, ether, and hexane, where the organic solvents used have a relatively low boiling point and can be quantitatively removed from the aqueous phase during the work-up of the reaction. The bulk reaction temperature is lower than in the previously described experiments. Here, both the phosphorane and the phosphonium salt can be employed with equal success as the Wittig olefination component (Table 1). It must be noted that the transformation of the phosphonium salt to the isolated phosphorane involves the use of a chlorinated solvent, usually dichloromethane, for extracting the phosphorane from the basic aqueous phase. Using the phosphonium salt in the above reaction avoids this process, which leads to a larger amount of wash water contaminated with dichloromethane, as well as drying and filtration procedures employed to obtain the pure phosphorane. After the actual ultrasound assisted, combined Suzuki coupling–Wittig olefination reaction, the product unfortunately still needs to be separated by column chromatography. This is in contrast to the ultrasound assisted Wittig olefination of conjugated phosphoranes with aldehydes,[7] run in a biphasic system of aq. Na_2CO_3 and hexane–ether, where the product can be siphoned off with the upper organic layer in sufficient purity without any further purification.

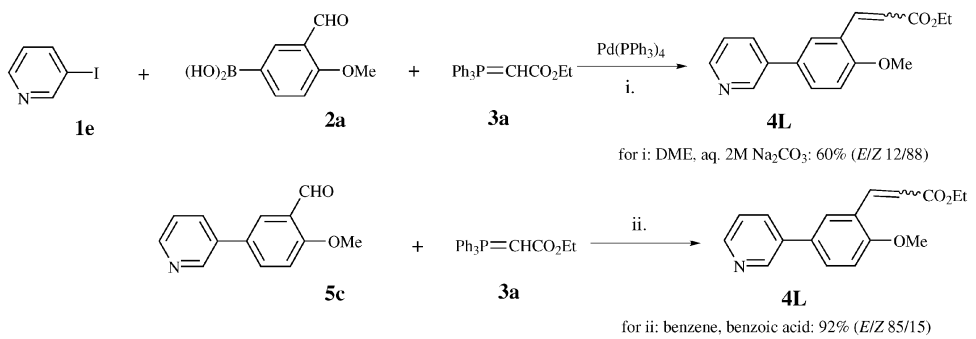
Conclusions

With formylboronic acids as central building blocks, biaryl/hetrarylacrylates, biaryl/hetarylenones, and acrylonitriles with extended π-systems can be synthesized in one step by a combined Suzuki cross-coupling–Wittig olefination reaction, where stabilized phosphoranes are used. The reaction can also be performed under ultrasound at ambient temperature in a biphasic system with the organic phase consisting of hexane and ether, which can be removed easily at the end of the reaction.

Experimental

General remarks

Melting points were measured on a Yanaco microscopic hot stage and are uncorrected. Infrared spectra were measured



Scheme 4 One-pot Suzuki–Wittig reaction with a halopyridine—*E* : *Z*-isomeric dependence on reaction conditions.

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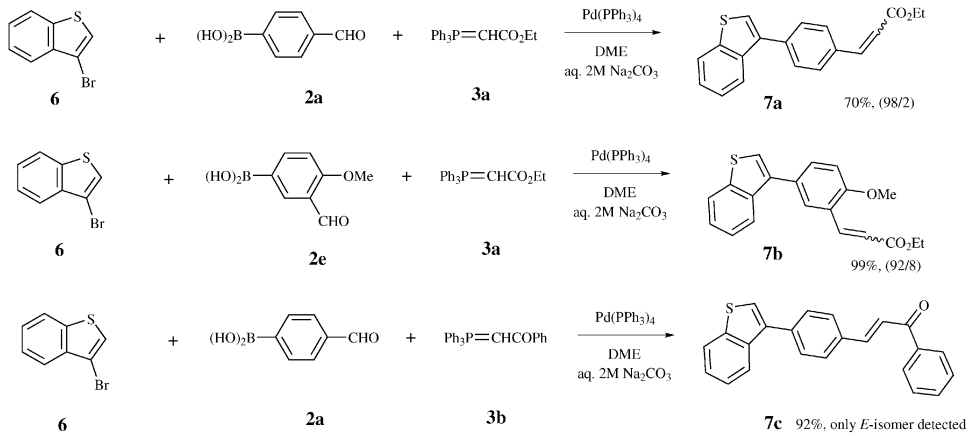

Scheme 5 One-pot Wittig–Suzuki reaction with 3-bromobenzo[*b*]thiophene [3-bromothianaphthene (**6**)].

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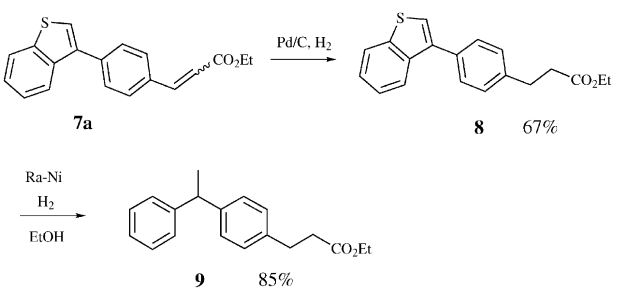
with a JASCO IR-700 instrument. ^{1}H (at 270 MHz and 395.7 MHz) and ^{13}C NMR (at 67.8 MHz and 99.45 MHz) were recorded with a JEOL EX-270 and a JEOL Lambda 400 FT-NMR spectrometer, respectively. The chemical shifts are relative to TMS (solvent $CDCl_3$, unless otherwise noted). Mass spectra were measured with a JMS-01-SG-2-spectrometer (EI, 70 eV). Column chromatography was carried out on Wakogel 300. For the ultrasonication, a 35 KHz Elma Transsonic T-460 bath was used. The sonication experiments were carried out at 35 °C. All experiments were purged with argon at the start.

All chemical reagents were of reagent grade. Ethoxycarbonylmethylidenetriphenylphosphorane (**3a**), while commercially available, was prepared according to a procedure by Considine.[11] Benzoylmethylidenetriphenylphosphoranes (**3b**) and acetylmethylidenetriphenylphosphorane (**3c**) were similarly prepared according to Ramirez and Dershowitz[12] from α-chlorobenzophenone and chloroacetone, respectively. Phosphorane **3d**[3c] was prepared by Suzuki cross-coupling from *p*-bromobenzoylmethylidenetriphenylphosphorane. Phosphorane **3h** was prepared according to Trippett and Walker[13] and phosphorane **3g** by reaction of triphenylphosphine and *N*-maleimide according to Hudson and Chopard.[14] 3-Bromobenzo[*b*]thiophene (**6**), also commercially available, was prepared by monobromination of benzo[*b*]thiophene. 4-(Thien-2′-yl)-benzaldehyde (**5a**) and 4-(thien-3′-yl)benzaldehyde (**5b**) were prepared by Suzuki cross-coupling of **2a** with **1a** and **1b**, respectively.

2-Formylthien-5-ylboronic acid (**2a**), 3-formyl-4-methoxyboronic acid (**2e**), 2-, 3- and 4-formylphenylboronic acids



Scheme 6 Reduction of benzo[*b*]thiophene **7a**.

2b–2d were used as purchased from Aldrich. Raney nickel (50%) was purchased from Kansai Shokubai Kagaku.

The products gained from the combined Suzuki coupling–Wittig olefination procedure were for the most part obtained as mixtures of *E*- and *Z*-isomers as marked in the text. When crystalline, the pure *E*-isomers were obtained by crystallisation from hexane–ether of the product mixture, which had already been purified by column chromatography. When oils, the pure *E*-isomers were obtained by careful chromatographic separation. Unless noted otherwise, the spectroscopic data given in the experimental part pertain to the *E*-isomer only, while the yield given is that of the *E*–*Z* isomeric mixture, with ratios as shown in the schemes.

Syntheses

Ethyl bisthienylacrylate (4a). A mixture of **1a** (163 mg, 1.0 mmol), **2a** (156 mg, 1.0 mmol), **3a** (715 mg, 2.1 mmol) and $Pd(PPh_3)_4$ (80 mg, 6.9×10^{-2} mmol) in a mixed solvent of DME (3 mL) and aq. Na_2CO_3 (2 M, 1.3 mL) was heated at 65 °C for 9 h. Then, $CHCl_3$ (10 mL) and water (10 mL) were added and the mixture was extracted with chloroform. The organic phase was dried over anhydrous $MgSO_4$ and was concentrated *in vacuo*. Column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4a** (230 mg, 87%). *E*-**4a**: pale yellow crystals; mp 51 °C. IR (KBr) ν 3070, 2978, 2934, 1704, 1622, 1451, 1368, 1328, 1300, 1272, 1224, 1203, 1163, 1040, 800, 697 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.33 (t, 3H, ^3J 7.0 Hz), 4.25 (q, 2H, ^3J 7.0 Hz), 6.18 (d, 1H, ^3J 15.7 Hz), 7.04 (dd, 1H, ^3J 5.1 Hz, ^3J 3.8 Hz), 7.10 (d, 1H ^3J 3.8 Hz), 7.15 (d, 1H, ^3J 3.8 Hz), 7.23 (dd, 1H, ^3J 3.8 Hz, ^4J 1.0 Hz), 7.26 (dd, 1H, ^3J 5.1 Hz, ^4J 1.0 Hz), 7.72 (d, 1H, ^3J 15.7 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.32, 60.49, 116.57, 124.29, 124.73, 125.57, 128.05, 132.07, 132.67, 136.67, 138.13, 140.24, 166.84 (C=O). MS (EI, 70 eV) m/z (%) = 264 (100, M^+), 236 (13), 219 (58), 192 (66). HRMS (Found) 264.0281. Calc. for $C_{13}H_{12}O_2S_2$: 264.0279. Anal. Calc. for $C_{13}H_{12}O_2S_2$ (264.3): C 59.07; H 4.58; found: C 59.34; H 4.66.

Ethyl 3-[5′-(thien-3″-yl)thien-2′-yl]acrylate (4b). 1b (163 mg, 1.0 mmol), **2a** (156 mg, 1.0 mmol), **3a** (700 mg, 2.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (3 mL) and 2 M aq. Na_2CO_3 (1.5 mL) were reacted at 85 °C for 8 h. The crude

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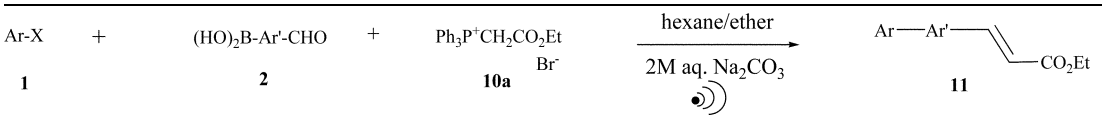
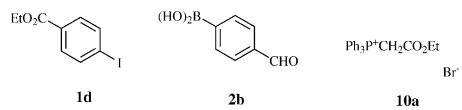
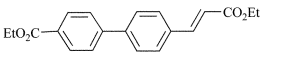
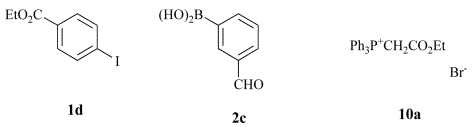
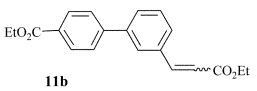
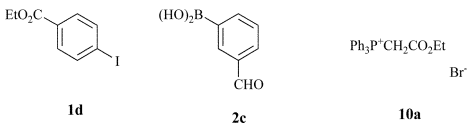
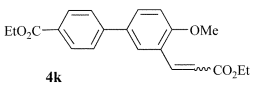
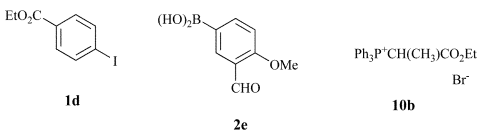
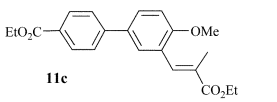
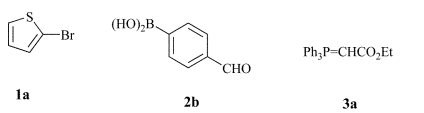
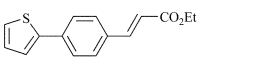
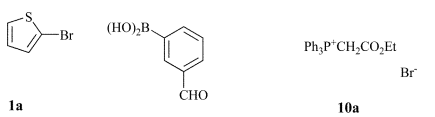
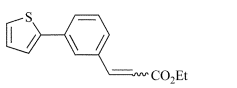
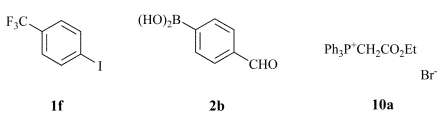
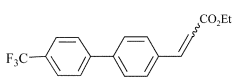
Table 1 One-pot Suzuki cross-coupling–Wittig olefination protocol under sonoirradiation



Starting materials	Reaction conditions	Products
 1d, 2b, 10a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 5 h.	 11a 85%, only *E*-isomer detected
 1d, 2c, 10a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 5.5 h.	 11b quant.; *E*/*Z* = 94/6
 1d, 2c, 10a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 5 h.	 4k 90%; *E*/*Z* = 99/1
 1d, 2e, 10b	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 8h.	 11c 87%; one isomer only
 1a, 2b, 3a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, DME, 2 M aq. Na_2CO_3, 6 h.	 4e 78%; only *E*-isomer detected
 1a, 2c, 10a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 5 h.	 11d quant., *E*/*Z* = 96/4
 1f, 2b, 10a	$Pd(OAc)_2$, $Pd(PPh_3)_4$, hexane–ether 10 : 1, 1.5 M aq. Na_2CO_3, 5 h.	 11e 60%; *E*/*Z* = 97/3

product was purified by column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) to give **4b** (224 mg, 85%). *E*-**4b**; slowly crystallizing yellow solid. IR (neat) ν 3084, 2976, 1708, 1626, 1273, 1207, 1165, 966, 853, 807, 773 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.33 (t, 3H, ^3J 7.5 Hz), 4.25 (q, 2H, ^3J 7.5 Hz), 6.24 (d, 1H, ^3J 15.6 Hz), 7.12–7.39 (m, 5H), 7.73 (d, 1H, ^3J 15.6 Hz). MS (EI, 70 eV) *m*/*z* (%) = 264 (100, M^+), 236 (15), 219 (50), 192 (61), 147 (14). HRMS (Found) 264.0280. Calc. for $C_{13}H_{12}O_2S_2$: 264.0279.

Ethyl 3-[2′-(4″-methoxyphenyl)-thien-5′-yl]acrylate (4c). 1c (234 mg, 1.0 mmol), **2a** (360 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 9 h. Column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4c** (268 mg, 93%). *E*-**4c**: pale yellow needles; mp 97.5 °C. IR (KBr) ν 2984, 2960, 2938, 1695, 1623, 1604, 1453, 1365, 1306, 1288, 1256, 1226, 1209, 1167, 1027, 972, 803 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.33 (t, 3H, ^3J 7.0 Hz), 3.84 (s, 3H, OCH_3), 4.25 (q, 2H, ^3J 7.0 Hz), 6.18 (d, 1H, ^3J 15.7 Hz), 6.93 (d, 2H, ^3J 8.6 Hz), 7.14 (d, 1H, ^3J 3.8 Hz), 7.18 (d, 1H, ^3J 3.8 Hz), 7.53 (d, 2H, ^3J 8.6 Hz), 7.72 (d, 1H, ^3J 15.7 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.33, 55.36, 60.48, 114.32 (2C), 117.71, 126.97, 128.09, 128.54 (2C),

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132.60, 132.78, 142.59, 144.19, 159.57, 167.11 (C=O). MS (EI, 70 eV) m/z (%) = 288 (21, M^+), 264 (32), 194 (43), 149 (38). HRMS (Found) 288.0820. Calc. for $C_{16}H_{16}O_3S$: 288.0820. Anal. calc. for $C_{16}H_{16}O_3S$ (288.4): C 66.64; H 5.59; found: C 66.63; H 5.62.

Ethyl 3-(*p*-methoxy-4′,4″-biphenyl)acrylate (4d). 1c (234 mg, 1.0 mmol), **2b** (300 mg, 2.0 mmol), **3a** (1.15 g, 3.3 mmol) and $Pd(PPh_3)_4$ (60 mg, 5.2×10^{-2} mmol) in a solvent mixture of DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 9 h. Column chromatography of the reaction product on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4d** (262 mg, 93%). *E*-**4d**: colorless solid; mp 135 °C. IR (KBr) ν 2980, 1707, 1630, 1600, 1497, 1308, 1256, 1194, 1173, 1034, 823 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz), 3.87 (s, 3H, OCH_3), 4.28 (q, 2H, ^3J 7.0 Hz), 6.45 (d, 1H, ^3J 16.2 Hz), 7.00 (d, 2H, ^3J 8.6 Hz), 7.56 (d, 2H, ^3J 8.6 Hz), 7.58 (bs, 4H), 7.72 (d, 1H, ^3J 16.2 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.34, 55.35, 60.43, 114.29 (2C), 116.00, 121.54, 122.83, 126.41, 127.29, 127.44 (2C), 132.41, 137.21, 137.77, 147.40, 159.88, 167.00 (C=O). MS (EI, 70 eV) m/z (%) 282 (100, M^+), 267 (3), 254 (8), 237 (20), 210 (14), 195 (10), 165 (14). HRMS (Found) 282.1258. Calc. for $C_{18}H_{18}O_3$: 282.1256. Anal. calc. for $C_{18}H_{18}O_3$ (282.3): C 76.57; H 6.43; found: C 76.14; H 6.42.

Ethyl 3-[4′-(thien-2″-yl)phenyl]acrylate (4e). 1a (163 mg, 1.0 mmol), **2b** (300 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 8 h. Column chromatography of the reaction mixture on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4e** (238 mg, 92%). *E*-**4e**: colorless solid; mp 102 °C. IR (KBr) ν 2982, 1707, 1633, 1600, 1531, 1501, 1427, 1366, 1327, 1308, 1207, 1171, 1117, 1092, 1027, 983, 818, 710 cm^{-1}. ^1H NMR (395.7 MHz, $CDCl_3$) δ 1.34 (t, 3H, ^3J 7.0 Hz), 4.27 (q, 2H, ^3J 7.0 Hz), 6.44 (d, 1H, ^3J 15.9 Hz), 7.09 (dd, 1H, ^3J 5.1 Hz, ^3J 3.6 Hz), 7.31 (dd, 1H, ^3J 5.1 Hz, ^4J 1.2 Hz), 7.37 (dd, 1H, ^3J 3.6 Hz, ^4J 1.2 Hz), 7.53 (d, 2H, ^3J 8.2 Hz), 7.62 (d, 2H, ^3J 8.2 Hz), 7.66 (d, 1H, ^3J 15.9 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.33, 60.50, 117.97, 123.78, 125.64, 126.10 (2C), 128.23, 128.63 (2C), 133.44, 136.11, 143.43, 143.84, 166.98 (C=O); MS (EI, 70 eV) m/z (%) 258 (100, M^+), 230 (13), 213 (57), 186 (32), 184 (33). HRMS (Found) 258.0712. Calc. for $C_{15}H_{14}O_2S$: 258.0715. Anal. calc. for $C_{15}H_{14}O_2S$ (258.3): C 69.74; H 5.46; found: C 69.94; H 5.46.

Ethyl 3-(*p*-methoxy-3′,4″-biphenyl)acrylate (4f). 1c (234 mg, 1.0 mmol), **2c** (300 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (80 mg, 6.9×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted for 9 h at 65 °C. Column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4f** (259 mg, 92%). *E*-**4f**: pale yellow oil. IR (neat): ν 2980, 2934, 2904, 2834, 1712, 1639, 1611, 1517, 1247, 1181, 1032, 833, 794 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz), 3.86 (s, 3H, OCH_3), 4.27 (q, 2H, ^3J 7.0 Hz), 6.49 (d, 1H, ^3J 15.9 Hz), 6.99 (d, 2H, ^3J 8.4 Hz), 7.46–7.58 (m, 5H), 7.69 (s, 1H), 7.74 (d, 1H, ^3J 15.9 Hz). MS (EI, 70 eV) m/z (%) = 282 (100, M^+), 267 (6), 254 (15), 237 (37), 195 (24), 165 (28). HRMS (Found) 282.1254. Calc. for $C_{18}H_{18}O_3$: 282.1256.

Ethyl 3-(*p*-methoxy-2′,4″-biphenyl)acrylate (4g). 1c (234 mg, 1.0 mmol), **2d** (300 mg, 2.0 mmol), **3a** (1.15 g, 3.3 mmol) and $Pd(PPh_3)_4$ (60 mg, 5.2×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 65 °C for 8 h. Column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) yielded **4g** (254 mg, 90%). *E*-**4g**: colorless oil. IR (neat): ν 3058, 2980, 2934, 2902, 2836, 1713, 1633, 1478, 1443, 1305, 1267, 1246, 1179, 835, 764 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.33 (t, 3H, ^3J 7.0 Hz, CH_3), 3.87 (s, 3H, OCH_3), 4.27 (q, 2H, ^3J 7.0 Hz, OCH_2), 6.62 (d, 1H, ^3J 15.9 Hz), 6.94 (d, 2H, ^3J 8.4 Hz), 7.17–7.43 (m, 6H), 8.00 (d, 1H, ^3J 15.9 Hz). MS (70 eV) m/z (%) 282 (91, M^+), 209 (100). HRMS (Found) 282.1255. Calc. for $C_{18}H_{18}O_3$: 282.1256.

Ethyl 3-[2′-(thien-2″-yl)phenyl]acrylate (4h). 1a (163 mg, 1.0 mmol), **2d** (300 mg, 2.0 mmol), **3a** (1.15 g, 3.3 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M Na_2CO_3 (2.5 mL) were reacted at 65 °C for 9 h. Column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) gave **4h** (232 mg, 90%). *E*-**4h**: pale yellow oil. IR (neat) ν 3062, 2980, 2936, 1900, 1712, 1634, 1478, 1448, 1366, 1315, 1270, 1178, 1036, 986, 851, 763, 702 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.32 (t, 3H, ^3J 7.0 Hz), 4.25 (q, 2H, ^3J 7.0 Hz), 6.41 (d, 1H, ^3J 16.1 Hz), 7.03 (dd, 1H, ^3J 3.6 Hz, ^4J 1.3 Hz), 7.13 (dd, 1H, ^3J 4.9 Hz, ^3J 3.6 Hz), 7.37–7.43 (m, 3H), 7.51 (m, 1H), 7.66 (m, 1H), 7.98 (d, 1H, ^3J 16.1 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.31, 60.45, 119.83, 126.44, 127.26, 127.62, 127.98, 128.86, 129.75, 130.84, 133.21, 135.04, 141.15, 143.62, 166.81; MS (70 eV): m/z (%) 258 (35), 213 (18), 185 (100), 184 (91), 152 (19). HRMS (Found) 258.0713. Calc. for $C_{15}H_{14}O_2S$: 258.0715.

Ethyl 3-(6′-methoxy-3′-(4″-methoxyphenyl)phenyl)acrylate (4i). 1c (234 mg, 1.0 mmol), **2e** (360 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (3 mL) were reacted at 75 °C for 9 h. Column chromatography of the reaction product on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) yielded **4i** (278 mg, 89%, *E*- : *Z*-**4i**: 86 : 14) as a pale yellow oil. *E*-**4i**: IR (neat) ν 2936, 2902, 2836, 1706, 1630, 1609, 1490, 1464, 1274, 1244, 1179, 1124, 1055, 1025, 814 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) δ 1.34 (t, 3H, ^3J 7.0 Hz, CH_3), 3.86 (s, 3H, OCH_3), 3.92 (s, 3H, OCH_3), 4.27 (q, 2H, ^3J 7.0 Hz, OCH_2), 6.59 (d, 1H, ^3J 15.9 Hz), 6.93–6.99 (m, 3H), 7.46–7.51 (m, 3H), 7.68 (d, 1H, ^4J 2.4 Hz), 8.02 (d, 1H, ^3J 15.9 Hz). MS (EI, 70 eV) m/z (%) 312 (100, M^+), 267 (11), 252 (26). HRMS (Found) 312.1364. Calc. for $C_{19}H_{20}O_4$: 312.1362.

Ethyl 3-[6′-methoxy-3′-(thien-2″-yl)phenyl]acrylate (4j). 1a (163 mg, 1.0 mmol), **2e** (360 mg, 2.0 mmol), **3a** (1.15 g, 3.3 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted for 8 h at 65 °C. Column chromatography of the reaction product on silica gel (hexane–$CHCl_3$–ether, 10 : 1 : 1) yielded **4j** (268 mg, 93%). *E*-**4j**: pale yellow crystals: mp 97 °C; IR (KBr) ν 2986, 1715, 1639, 1491, 1293, 1256, 1179, 1029, 987, 698 cm^{-1}; ^1H NMR (395.7 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz), 3.93

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(s, 3H, OCH_3), 4.28 (q, 2H, ^3J 7.0 Hz), 6.58 (d, 1H, ^3J 16.2 Hz), 6.93 (d, 1H, ^3J 8.5 Hz), 7.06 (dd, 1H, ^3J 3.6 Hz, ^3J 5.1 Hz), 7.22 (dd, 1H, ^3J 3.6 Hz, ^4J 1.0 Hz), 7.24 (dd, 1H, ^3J 5.1 Hz, ^4J 1.0 Hz), 7.58 (dd, 1H, ^3J 8.5 Hz, ^4J 2.4 Hz), 7.73 (d, 1H, ^4J 2.4 Hz), 7.99 (d, 1H, ^3J 16.2 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.32, 55.36, 60.53, 114.30, 118.51, 126.20, 126.43, 128.15, 128.59, 129.26, 132.90, 134.89, 141.51, 144.61, 159.43, 166.98. MS (EI, 70 eV) m/z (%) 288 (100, M^+), 243 (15), 229 (29), 200 (26). HRMS (Found) 288.0819. Calc. for $C_{16}H_{16}O_3S$: 288.0820. Anal. calc. for $C_{16}H_{16}O_3S$ (288.4): C 66.64; H 5.59; found: C 66.87; H 5.63.

Ethyl 3-[6′-methoxy-3′-(4″-ethoxycarbonylphenyl)phenyl]-acrylate (4k). 1d (276 mg, 1.0 mmol), **2e** (360 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 9 h. Column chromatography on silica gel (hexane–$CHCl_3$–ether, 10 : 1 : 1) yielded **4k** (350 mg, 99%). *E*-**4k**: colorless solid, mp 105 °C. IR (KBr) ν 2976, 1706, 1603, 1488, 1392, 1366, 1273, 1195, 1111, 1051, 1022, 996, 770 cm^{-1}; ^{1}H NMR (395.7 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz), 1.41 (t, 3H, ^3J 7.0 Hz), 3.95 (s, 3H, OCH_3), 4.28 (q, 2H, ^3J 7.0 Hz, OCH_2), 4.41 (q, 2H, ^3J 7.0 Hz), 6.61 (d, 1H, ^3J 16.1 Hz), 6.82 (d, 1H, ^3J 8.4 Hz), 7.38 (m, 1H), 7.59–7.69 (m, 3H), 7.77 (d, 1H, ^4J 2.2 Hz), 8.11 (d, 1H, ^3J 8.5 Hz), 8.03 (d, 1H, ^3J 16.1 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.38 (2C), 55.72, 60.45, 60.98, 111.60, 119.49, 123.87, 126.44, 127.63 (2C), 128.97, 130.05 (2C), 132.54, 135.19, 139.67, 144.41, 158.37, 166.46, 167.32; MS (70 eV) m/z (%) 354 (100, M^+), 309, 295, 262, 183. HRMS (Found) 354.1469. Calc. for $C_{21}H_{22}O_5$: 354.1467.

Ethyl 3-[6′-methoxy-3′-pyrid-3″-ylphenyl]acrylate (4L). Method A: **1e** (205 mg, 1 mmol), **2e** (360 mg, 2.0 mmol), **3a** (1.15 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) were reacted at 65 °C for 9 h. Column chromatography of the reaction product on silica gel (hexane–ether–$CHCl_3$, 3 : 3 : 1 to ether–hexane–$CHCl_3$ 3 : 1 : 1) yielded **4L** (170 mg, 60%), mixture of (*E*)- and (*Z*)-isomers > *E*-**4L** : *Z*-**4L** = 12 : 88] as a light yellow oil. *Z*-**4L**: IR (neat) ν 2978, 2836, 1715, 1630, 1609, 1502, 1474, 1427, 1288, 1257, 1179, 1022, 802 cm^{-1}. ^{1}H NMR (395.7 MHz, $CDCl_3$) δ 1.18 (t, 3H, ^3J 7.0 Hz), 3.89 (s, 3H, OCH_3), 4.13 (q, 2H, ^3J 7.0 Hz), 6.04 (d, 1H, ^3J 12.3 Hz), 6.99 (d, 1H, ^3J 8.4 Hz), 7.20 (d, 1H, ^3J 12.3 Hz), 7.34 (m, 1H), 7.55 (m, 1H), 7.84 (bs, 2H), 8.55 (m, 1H), 8.83 (bs, 1H). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.09, 55.72, 60.20, 110.81, 120.69, 123.50, 124.63, 128.79, 129.40, 129.67, 133.93, 136.06, 138.55, 147.95, 148.00, 157.23, 166.13. MS (EI, 70 eV) m/z (%) 283 (100, M^+), 252 (17), 238 (30), 224 (57), 195 (18), 167 (16). HRMS (Found) 283.1204. Calc. for $C_{17}H_{17}O_3N$: 283.1208.

Method B: A solution of **1e** (213 mg, 1.0 mmol), **2e** (522 mg, 1.5 mmol) and benzoic acid (68 mg, 0.56 mmol) was heated at 75 °C for 9 h. The cooled solution was concentrated *in vacuo* and the residue was purified by column chromatography on silica gel (ether–$CHCl_3$, 3 : 1) to give **4L** (260 mg, 92%), (*E*)- and (*Z*)-isomers [*E*-**4L** : *Z*-**4L** = 85 : 15], as a colorless oil. *E*-**4L**: IR (KBr) ν 3050, 2988, 2840, 1713, 1632, 1181, 721 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz), 3.87 (s, 3H, OCH_3), 4.27 (q, 2H, ^3J 7.0 Hz), 6.60 (d, 1H, ^3J 15.9 Hz), 7.01 (d, 1H, ^3J 8.5 Hz), 7.36 (m, 1H), 7.40–7.60 (m, 2H), 7.77 (m, 1H), 8.02 (d, 1H, ^3J 15.9 Hz), 8.27 (m, 1H), 8.82 (d, 1H, ^4J 1.6 Hz). MS (70 eV) m/z (%) 283 (17), 252 (3). HRMS (Found) 283.1213. Calc. for $C_{17}H_{17}O_3N$: 283.1208.

(*E*)-1-(4′-Thien-2″-ylphenyl)-2-benzoylethene (4m). 1a (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3b** (1.08 g, 2.8 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 10 h. Column chromatography of the reaction mixture on silica gel (hexane–$CHCl_3$–ether, 10 : 2 : 1) gave **4m** (283 mg, 98%) as pale yellow needles, mp 133 °C. IR (KBr) ν 1659, 1633, 1599, 1336, 1219, 980, 820, 688 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$) δ 7.11 (dd, 1H, ^3J 5.1 Hz, ^3J 3.8 Hz), 7.33 (dd, 1H, ^3J 5.1 Hz, ^4J 1.1 Hz), 7.40 (dd, 1H, ^3J 3.8 Hz, ^4J 1.1 Hz), 7.48–7.59 (m, 3H), 7.51 (d, 1H, ^3J 15.7 Hz), 7.66 (vs, 4H), 7.82 (d, 1H, ^3J 15.7 Hz), 8.03 (m, 2H). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 121.72, 121.74, 125.80, 126.19 (2C), 128.28, 128.43 (2C), 128.63 (2C), 129.22 (2C), 132.79, 133.86, 136.45, 138.26, 143.43, 144.20, 190.46. MS (EI, 70 eV) m/z (%) 290 (100, M^+), 261 (6), 213 (18), 184 (22), 160 (19). HRMS (Found) 290.0765. Calc. for $C_{19}H_{14}OS$: 290.0765. Anal. calc. for $C_{19}H_{14}OS$ (290.4): C 78.59; H 4.86; found: C 78.77; H 4.90.

(*E*)-1-(4′-Thienyl-2″-ylphenyl)-2-(2‴,5‴-dimethoxybenzoyl) ethene (4n). 1a (35 mg, 0.21 mmol), **2a** (32 mg, 0.21 mmol), **3c** (95 mg, 0.21 mmol) and $Pd(PPh_3)_4$ (12 mg, 1×10^{-5} mmol) in DME (1 mL) and 2 M aq. Na_2CO_3 (0.5 mL) were reacted at 75 °C for 10 h. Column chromatography on silica gel (hexane–$CHCl_3$–ether, 5 : 1 : 1) gave **4n** (68 mg, 91%) as a slowly crystallizing pale yellow solid. IR (KBr) ν 2934, 1650, 1586, 1493, 1412, 1329, 1222, 1165, 1037, 819, 726 cm^{-1}. ^{1}H NMR (395.75 MHz, $CDCl_3$) δ 3.81 (s, 3H, OCH_3), 3.88 (s, 3H, OCH_3), 6.95 (d, 1H, ^3J 8.9 Hz), 7.04 (dd, 1H, ^3J 8.9 Hz, ^4J 3.6 Hz), 7.10 (dd, 1H, ^3J 5.1 Hz, ^3J 3.6 Hz), 7.20 (dd, 1H, ^3J 3.6 Hz, ^4J 1.2 Hz), 7.32 (dd, 1H, ^3J 5.1 Hz, ^4J 1.2 Hz), 7.38 (d, 1H, ^4J 3.6 Hz), 7.43 (d, 1H, ^3J 15.9 Hz), 7.60 (d, 2H, ^3J 8.5 Hz), 7.63 (d, 1H, ^3J 15.9 Hz), 7.64 (d, 2H, ^3J 8.5 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 55.91, 56.56, 113.39, 114.39, 119.18, 123.79, 125.65, 126.12 (2C), 126.60 (2C), 128.24, 129.03, 129.68, 134.17, 136.15, 142.56, 143.52, 152.57, 153.63, 192.39. MS (EI, 70 eV) m/z (%) 350 (54, M^+), 243 (100), 165 (47). HRMS (Found) 350.0978. Calc. for $C_{21}H_{18}O_3S$: 350.0977.

(*E*)-1-(4′-Thienyl-2″-ylphenyl)-2-(4‴-(*p*-trifluoromethylphenyl) benzoyl)ethene (4o). 1a (64 mg, 0.43 mmol), **2a** (70 mg, 0.43 mmol), **3d** (220 mg, 0.42 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (2 mL) and 2 M aq. Na_2CO_3 (1 mL) were reacted at 75 °C for 10 h. Column chromatography on silica gel (hexane–$CHCl_3$–ether, 1 : 1.5 : 1) gave **4o** (88 mg, 48%) as grayish plates, 261 °C. IR (KBr) ν 1658, 1596, 1329, 1124, 1074, 815, 700 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$–DMSO-d_6, 10 : 1 [v/v]) δ 7.13 (dd, 1H, ^3J 5.2 Hz, ^3J 3.7 Hz), 7.32 (dd, 1H, ^3J 3.7 Hz, ^4J 1.2 Hz), 7.36–7.87 (m, 13H), 8.12 (d, 2H, ^3J 10.2 Hz). MS (EI, 70 eV) m/z (%) 434 (32, M^+), 153 (49), 77 (100). HRMS (Found) 434.0953. Calc. for $C_{26}H_{17}OF_3S$: 434.0952. Anal. calc. for $C_{26}H_{17}OF_3S$ (434.4): C 71.88; H 3.94; found: C 72.00; H 4.12.

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Ethyl (*E*)-3-[4′-(thien-2″-yl)phenyl]methacrylate (4p). 1a (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3e** (1.17 g, 3.25 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-5} mol) in DME (5 mL) and 2.5 M aq. Na_2CO_3 (2.5 mL) were heated at 75 °C for 9 h. Column chromatography of the reaction mixture on silica gel gave **4p** (257 mg, 94%) as an oil. IR (neat) ν 2980, 1705, 1253, 1206, 1111, 1029 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz, OCH_2CH_3), 2.16 (d, 3H, ^4J 1.6 Hz, CH_3), 4.29 (q, 2H, ^3J 7.0 Hz, OCH_2), 7.11 (dd, 1H, ^3J 5.1 Hz, ^3J 3.8 Hz), 7.30 (dd, 1H, ^3J 5.1 Hz, ^4J 1.3 Hz), 7.35 (dd, 1H, ^3J 3.8 Hz, ^4J 1.3 Hz), 7.42 (d, 2H, ^3J 7.6 Hz), 7.66 (d, 2H, ^3J 7.6 Hz), 7.69 (q, 1H, ^4J 1.6 Hz). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 15.17, 15.30, 61.86, 124.47, 126.26, 126.66 (2C), 129.11, 129.55, 131.29 (2C), 135.24, 136.00, 138.98, 144.69, 169.61. MS (EI, 70 eV) *m*/*z* (%) 272 (100, M^+), 227 (37), 198 (94), 165 (49), 115 (34). HRMS (Found) 272.0872. Calc. for $C_{16}H_{16}O_2S$: 272.0871.

(*E*)-4-(4′-[Thien-2″-yl]phenyl)but-3-en-2-one (4q). 1a (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3f** (1.05 g, 3.3 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were reacted at 75 °C for 10 h. Column chromatography of the reaction mixture on silica gel (hexane–$CHCl_3$–ether, 10 : 2 : 1) gave **4q** (221 mg, 97%) as a colorless solid, mp 156 °C. IR (KBr) ν 3074, 1657, 1601, 1424, 1358, 1267, 1255, 978, 721, 701 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 2.39 (s, 3H, CH_3), 6.72 (d, 1H, ^3J 16.5 Hz), 7.09 (dd, 1H, ^3J 5.1 Hz, ^3J 3.8 Hz), 7.33 (dd, 1H, ^3J 5.1 Hz, ^4J 1.1 Hz), 7.38 (dd, 1H, ^3J 3.8 Hz, ^4J 1.1 Hz), 7.51 (d, 1H, ^3J 16.5 Hz), 7.53 (d, 2H, ^3J 8.4 Hz), 7.65 (d, 2H, ^3J 8.4 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 27.56, 123.91, 125.79, 126.17, 126.81 (2C), 128.27 (2C), 128.88, 133.37, 136.42, 142.72, 143.34, 198.29. MS (EI, 70 eV) *m*/*z* (%) 228 (100, M^+), 213 (92), 184 (38), 152 (14), 139 (11), 115 (13). HRMS (Found) 228.0610. Calc. for $C_{14}H_{12}OS$: 228.0609. Anal. calc. for $C_{14}H_{12}OS$ (228.3): C 73.65; H 5.30; found: C 73.45; H 5.32.

(*E*)-3-(4′-Thien-2″-ylphenyl)methylidenyl-*N*-phenyl-4(*H*)-maleimide (4r). A mixture of **1a** (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3g** (1.3 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) was heated to 75 °C for 9 h. The reaction products were separated by column chromatography on silica gel (ether–chloroform–hexane, 2 : 1 : 1) to give **4r** (110 mg, 32%) as a colorless solid, mp 286 °C. IR (KBr) ν 1770, 1706 (s), 1658, 1598, 1497, 1389, 1196, 1175, 718, 701 cm^{-1}. ^1H NMR (270 MHz, DMSO-d_6) δ 3.87 (bs, 2H), 7.18 (m, 1H), 7.35 (d, 2H, ^3J 7.3 Hz), 7.40–7.56 (m, 3H), 7.57 (bs, 1H), 7.62 (bd, 1H, ^3J 5.1 Hz), 7.65 (bd, 1H, ^3J 3.8 Hz), 7.73 (d, 2H, ^3J 8.4 Hz), 7.78 (d, 2H, ^3J 8.4 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 32.22, 124.80 (2C), 124.89, 125.11, 125.74, 126.85 (2C), 127.15, 128.27 (2C), 128.84 (2C), 131.20, 132.04, 132.63, 133.21, 134.97, 142.41, 169.97, 173.46. MS (EI, 70 eV) *m*/*z* (%) 345 (9) [M^+], 198 (10), 153 (44), 136 (39), 77 (100). HRMS (Found) 345.0824. Calc. for $C_{21}H_{15}O_2NS$: 345.0824.

2-Methoxy-5-(pyrid-3′-yl)-benzaldehyde (5c)[15,16]. A mixture of **1e** (410 mg, 2.0 mmol), **2a** (720 mg, 4.0 mmol), and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (10 mL) and 2 M Na_2CO_3 (5 mL) was reacted at 75 °C for 9 h. Thereafter, the cooled reaction mixture was diluted with water (10 mL) and extracted with $CHCl_3$ (2×15 mL). The combined organic phase was dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel (ether–hexane–$CHCl_3$, 3 : 3 : 1 to ether) to give **5c** (410 mg, 96%) as a colorless powder, mp 86 °C. IR (KBr) ν 3000, 2876, 1679, 1613, 1505, 1427, 1276, 1192, 1015, 800, 708 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 4.00 (s, 3H, OCH_3), 7.13 (d, 1H, ^3J 8.6 Hz), 7.37 (m, 1H), 7.80 (dd, 1H, ^3J 8.6 Hz, ^4J 2.3 Hz), 7.88 (m, 1H), 8.07 (d, 1H, ^4J 2.3 Hz), 8.59 (dd, 1H, ^3J 4.9 Hz, ^4J 1.7 Hz), 8.83 (dd, 1H, ^4J 2.6 Hz, ^4J 1.0 Hz), 10.53 (s, 1H, C*H*O). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 55.92, 112.50, 123.58, 125.15, 126.94, 130.45, 133.91, 134.20, 135.07, 147.90, 148.54, 161.75, 189.43 (*C*HO). MS (70 eV) *m*/*z* (%) 213 (100, M^+), 196, 167, 153. HRMS (Found) 213.0791. Calc. for $C_{13}H_{11}O_2N$: 213.0790. Anal. calc. for $C_{13}H_{11}O_2N$ (213.2): C 73.22; H 5.20; N 6.37; found: C 73.06; H 5.18; N 6.58.

3-[4′-(Thien-2″-yl)phenyl]3-acrylonitrile (4s). Method A: **1a** (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3h** (995 mg, 3.3 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3×10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 were reacted at 75 °C for 9 h. The reaction products were separated by column chromatography (hexane–$CHCl_3$–ether, 10 : 2 : 1) to give **4s** (206 mg, 98%) as a 63 : 37 mixture of *E*- : *Z*-isomers.

Method B: **5a** (286 mg, 1.5 mmol) and **3h** (895 mg, 3.0 mmol) in a mixture of DME (10 mL) and 2 M aq. Na_2CO_3 (5 mL) were reacted at 75 °C for 9 h. The reaction products were separated by column chromatography on silica gel to give **4s** (284 mg, 89%) as a 91 : 9 mixture of *E*- : *Z*- isomers.

Method C: a solution of **5a** (385 mg, 2.05 mmol), **3h** (1.2 g, 4.1 mmol) and benzoic acid (170 mg, 1.39 mmol) in deaerated benzene (15 mL) was kept at 75 °C for 9 h. Then, the cooled solution was concentrated and the residue was separated by column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) to give **4s** as a mixture of isomers (*E* : *Z*, 97 : 3) (410 mg, 95%). *E*-**4s**: IR (KBr) ν 2212, 1602, 1424, 975, 806, 707 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 5.91 (d, 1H, ^3J 16.5 Hz), 7.10 (dd, 1H, ^3J 5.1 Hz, ^3J 4.0 Hz), 7.34 (dd, 1H, ^3J 5.1 Hz, ^3J 1.2 Hz), 7.38 (dd, 1H, ^3J 4.0 Hz, ^4J 1.2 Hz), 7.39 (d, 1H, ^3J 16.5 Hz), 7.45 (d, 2H, ^3J 8.6 Hz), 7.65 (d, 2H, ^3J 8.6 Hz). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 95.88, 118.25, 124.34, 126.14, 126.26 (2C), 128.01 (2C), 128.37, 132.44, 137.13, 143.02, 149.79. MS (70 eV) *m*/*z* 211 (100, M^+), 166 (9), 139 (7). HRMS (Found) 211.0456. Calc. for $C_{13}H_9NS$: 211.0456. Anal. calc. for $C_{13}H_9NS$ (211.3): C 73.90; H 4.29; N 6.66; found: C 73.89; H 4.35; N 6.62.

Method D: a solution of **1a** (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3a** (995 mg, 3.3 mmol) and $Pd(PPh_3)_4$ (90 mg, 7.7×10^{-2} mmol) in benzene (10 mL) and 2 M aq. Na_2CO_3 was reacted at 75 °C for 9 h and separated as above to give **4s** (167 mg, 79%) as a 91 : 9 mixture of *E* : *Z*-isomers.

(*E*)-3-[4′-(Thien-2″-yl)phenyl]-acrylamide (4t). H_2O_2 (aq., 30 wt%, 10 mL) was given dropwise to a mixture of **4s** (418 mg, 2.0 mmol), tetrabutylammonium hydrogensulfate (410 mg, 1.2 mmol) in CH_2Cl_2 (50 mL).[17] Thereafter, aq. NaOH (20 wt%, 8 mL) was added at 0 °C. The resulting mixture was stirred at rt for 4 h. Thereafter water (15 mL) was added and the mixture

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was extracted with CH_2Cl_2 (3 × 15 mL). The organic phase was dried over $MgSO_4$ and concentrated *in vacuo*. The residue was separated on silica gel (ether to ether–ethyl acetate) to give **4t** (256 mg, 56%) as a colorless solid, mp 243 °C. IR (KBr) ν 3400, 3165, 1675, 1620, 1415, 1405, 1243, 979, 825, 707 cm^{-1}. ^1H NMR (270 MHz, DMSO-d_6) δ 6.62 (d, 1H, ^3J 15.9 Hz), 7.08 (bs, 1H), 7.16 (m, 1H), 7.42 (d, 1H, ^3J 15.9 Hz), 7.52 (bs, 1H), 7.55 (m, 2H), 7.57 (d, 2H, ^3J 8.1 Hz), 7.69 (d, 2H, ^3J 8.1 Hz). ^{13}C NMR (67.8 MHz, DMSO-d_6) δ 122.19, 124.25, 125.68 (2C), 126.24, 128.28 (2C), 128.62, 133.34, 134.55, 138.40, 142.65, 166.58. MS (FAB, 3-nitrobenzyl alcohol) *m*/*z* (%) 230 (MH^+, 16). HRMS (Found) 230.0635. Calc. for $C_{13}H_{12}ONS$: 230.0640 (FAB, MH^+). Anal. calc. for $C_{13}H_{11}ONS$ (229.3): C, 68.09; H, 4.84; N, 6.11; found: C, 68.33; H, 4.84; N, 6.12.

3-[4′-(Thien-3″-yl)phenyl]-acrylonitrile (4u). Method A: a mixture of **1b** (163 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3h** (995 mg, 3.3 mmol), $Pd(PPh_3)_4$ (50 mg, 4.3 × 10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) was reacted at 65 °C for 9 h. Column chromatography of the reaction product on silica gel (hexane–ether–$CHCl_3$, 5 : 2 : 1) provided **4u** (205 mg, 97%) as a mixture of *E*- and *Z*-isomers (*E* : *Z*, 1 : 0.9), which was not separated further, colorless solid, mp 105 °C. IR (KBr) [*E*/*Z*-(**4u**)] ν 3102, 2212, 1602, 1530, 1427, 1206, 1187, 975, 870, 851, 815, 785 cm^{-1}. ^1H NMR (395.7 MHz, $CDCl_3$) δ *Z*-(**4u**): 5.44 (d, 1H, ^3J 12.1 Hz), 7.12 (d, 1H, ^3J 12.1 Hz), 7.47 (m, 2H), 7.55 (m, 1H), 7.67 (d, 2H, ^3J 8.2 Hz), 7.86 (d, 2H, ^3J 8.2 Hz). *E*-(**4u**): 5.88 (d, 1H ^3J 16.7 Hz), 7.41 (d, 1H, ^3J 16.7 Hz), 7.47 (m, 2H), 7.51 (d, 2H, ^3J 8.4 Hz), 7.55 (m, 1H), 7.63 (d, 2H, ^3J 8.4 Hz). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 95.84, 118.33, 121.65, 126.05, 126.83, 126.97 (2C), 128.01 (2C), 132.34, 138.07, 141.02, 150.03. MS (EI, 70 eV) *m*/*z* (%) 211 (38, M^+). HRMS (Found) 211.0459. Calc. for $C_{13}H_9NS$: 211.0459. Anal. calc. for $C_{13}H_9NS$ (211.3): C 73.90; H 4.29; N 6.66; found: C 73.96; H 4.38; N 6.71.

Method B: a solution of **5b** (282 mg, 1.5 mmol), **3h** (850 mg, 2.8 mmol) and benzoic acid (75 mg, 0.61 mmol) in deaerated benzene (15 mL) was kept at 75 °C for 9 h. Then, the cooled solution was concentrated and the residue was separated by column chromatography on silica gel (hexane–ether–$CHCl_3$, 10 : 1 : 1) to give **4u** as a mixture of isomers (*E* : *Z*, 95 : 5) (310 mg, 98%).

3-[4′-(2″-Ethoxycarbonylethenyl)phenyl]benzo[*b*]thiophene (7a). 6 (639 mg, 3.0 mmol), **2a** (500 mg, 3.33 mmol), **3a** (1.22 g, 3.5 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3 × 10^{-2} mmol) in a solvent mixture of DME (20 mL) and 2 M aq. Na_2CO_3 (14 mL) were reacted at 75 °C for 9 h. Column chromatography of the reaction product on silica gel (hexane–ether–chloroform, 5 : 1 : 1) provided **7a** (650 mg, 70%). *E*-**7a**: colorless solid; mp 98 °C. IR (KBr) ν 3110, 3066, 2978, 2924, 1707, 1632, 1607, 1321, 1309, 1175, 1032, 991, 824, 808, 764, 734 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.36 (t, 3H, ^3J 7.0 Hz), 4.29 (q, 2H, ^3J 7.0 Hz), 6.48 (d, 1H, ^3J 15.9 Hz), 7.31–7.43 (m, 3H), 7.62 (bs, 4H), 7.75 (d, 1H, ^3J 15.9 Hz), 7.88–7.94 (m, 2H). MS (EI, 70 eV) *m*/*z* (%) 308 (100, M^+), 280 (10), 263 (21), 234 (24). HRMS (Found) 308.0872. Calc. for $C_{19}H_{16}O_2S$: 308.0871. Anal. calc. for $C_{19}H_{16}O_2S$ (308.4): C 74.00; H 5.23; found: C 74.22; H 5.29.

3-[5′-(2″-Ethoxycarbonylethenyl)-2′-methoxyphenyl]benzo[*b*]thiophene (7b). A mixture of **6** (426 mg, 2.0 mmol), **2e** (720 mg, 2.0 mmol), **3a** (2.2 g, 6.3 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3 × 10^{-2} mmol) in DME (10 mL) and 2 M aq. Na_2CO_3 (5 mL) were reacted at 65 °C for 9 h. Chromatography of the reaction product on silica gel (hexane–ether–$CHCl_3$, 5 : 1 : 1) provided **7b** (670 mg, 99%; *E*-**7b** : *Z*-**7b**, 92 : 8) as an oil. *E*-**7b**: IR (neat) ν 2960, 1714, 1634, 1488, 1030, 989, 818, 736 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.36 (t, 3H ^3J 7.3 Hz), 3.94 (s, 3H, OCH_3), 4.27 (q, 2H, ^3J 7.3 Hz), 6.58 (d, 1H, ^3J 16.2 Hz), 7.04 (d, 1H, ^3J 8.3 Hz), 7.36 (s, 1H), 7.35–7.43 (m, 2H), 7.56 (dd, 1H, ^3J 8.3 Hz, ^4J 2.2 Hz), 7.73 (d, 1H, ^4J 2.2 Hz), 7.84–7.93 (m, 2H), 8.04 (d, 1H, ^3J 16.2 Hz). MS (EI, 70 eV) *m*/*z* (%) 338 (100, M^+), 310 (3), 293 (8), 279 (17), 268 (15), 250 (23), 221 (19), 211 (11), 195 (6), 149 (14). HRMS (Found) 338.0977. Calc. for $C_{20}H_{18}O_3S$: 338.0977.

(*E*)-3-(4′-[2″-Benzoylethenyl]phenyl)benzo[*b*]thiophene (7c). A mixture of **6** (213 mg, 1.0 mmol), **2a** (300 mg, 2.0 mmol), **3b** (1.08 g, 3.0 mmol) and $Pd(PPh_3)_4$ (50 mg, 4.3 × 10^{-2} mmol) in DME (5 mL) and 2 M aq. Na_2CO_3 (2.5 mL) were held at 75 °C for 9 h. The reaction mixture was separated by column chromatography on silica gel (hexane–chloroform–ether, 3 : 2 : 1) to give **7c** (313 mg, 92%) as a yellow solid. IR (KBr) ν 3059, 1659, 1599, 1433, 1331, 1214, 1016, 750, 691 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 7.37–7.71 (m, 6H), 7.60 (d, 1H, ^3J 15.7 Hz), 7.66 (d, 2H, ^3J 8.2 Hz), 7.78 (d, 2H, ^3J 8.2 Hz), 7.88 (d, 1H, ^3J 15.7 Hz), 7.94 (m, 2H), 8.06 (m, 2H). MS (70 eV) *m*/*z* 340 (24, M^+), 284 (37), 266 (22), 253 (26), 238 (100), 207 (67). HRMS (Found) 340.0923. Calc. for $C_{23}H_{16}OS$: 340.0922.

3-[4′-(2″-Ethoxycarbonylethyl)phenyl]benzo[*b*]thiophene (8). **7a** (600 mg, 1.95 mmol) and 10 wt% Pd/C (245 mg, 0.23 mmol Pd) in a solvent mixture of EtOH (75 mL) and benzene (75 mL) were stirred under hydrogen atmosphere for 2 d. The progress of the reaction was monitored by periodic sampling and ^1H NMR determination of the crude mixture. After the reaction was finished, Pd/C was filtered off and the filtrate was concentrated *in vacuo*. Column chromatography of the residue on silica gel (hexane–ether, 3 : 1) gave **8** (408 mg, 67%) as a colorless oil. IR (neat): ν 2980, 1730, 1495, 1427, 1182, 762, 736 cm^{-1}. ^1H NMR (395.7 MHz, $CDCl_3$): δ 1.26 (t, 3H, ^3J 7.2 Hz), 2.69 (t, 2H, ^3J 7.5 Hz), 3.03 (t, 2H, ^3J 7.5 Hz), 4.16 (q, 2H, ^3J 7.2 Hz), 7.32 (d, 2H, ^3J 8.0 Hz), 7.38 (s, 1H), 7.39 (m, 2H), 7.52 (d, 2H, ^3J 8.0 Hz), 7.91 (m, 2H). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.23, 30.71, 35.85, 60.46, 122.90, 123.15, 124.27, 124.36, 127.19 (2C), 128.67 (2C), 128.71, 128.77, 133.97, 137.83, 139.96, 140.66, 172.88 (C═O); MS (EI, 70 eV) *m*/*z* (%) 310 (40, M^+), 254 (77), 223 (27), 180 (100), 167 (78). HRMS (Found) 310.1029. Calc. for $C_{19}H_{18}O_2S$: 310.1028.

Methyl 3-(4′[-1″-phenylethyl]phenyl)propionate (9). To a suspension of freshly prepared[18] Raney nickel (750 mg, 50 wt%) in ethanol (10 mL) was added **8** (400 mg, 1.29 mmol). The mixture was stirred at rt under a hydrogen atmosphere (1 bar) for 15 h. Then, the metal was filtered off, the reaction mixture concentrated *in vacuo* to dryness and the residue was subjected

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to column chromatography on silica gel (hexane–ether, 10 : 1) to give **9** (310 mg, 85%) as a colorless oil. IR (neat): ν 3024, 2970, 2928, 1737, 1511, 1493, 1451, 1372, 1290, 1181, 700 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.23 (t, 3H, ^3J 7.5 Hz), 1.61 (d, 3H, ^3J 7.3 Hz), 2.61 (t, 2H, ^3J 7.5 Hz), 2.89 (t, 2H, ^3J 7.5 Hz), 4.11 (sept., 1H, ^3J 7.3 Hz), 4.13 (q, 2H, ^3J 7.5 Hz), 7.08–7.32 (m, 9H). MS (70 eV) m/z (%) 282 (79, M^+), 267 (100), 193 (60). HRMS (Found): 282.1617. Calc. for $C_{19}H_{22}O_2$: 282.1620.

(*E*)-Ethyl 3-(5′-[4″-ethoxycarbonylphenyl]phenyl)methacrylate (11c). General procedure for one-pot Suzuki coupling–Wittig olefination under ultrasonication. A solution of **1d** (276 mg, 1.0 mmol), **2e** (360 mg, 2.0 mmol), **10b** (1.10 g, 2.5 mmol), $Pd(PPh_3)_4$ (15 mg, 1.3×10^{-2} mmol) and $Pd(OAc)_2$ (20 mg, 8.9×10^{-2} mmol) in a biphasic mixture of 2 M Na_2CO_3 (10 mL), hexane (10 mL) and ether (2 mL) was placed in a straight bottomed flask tightly covered with Saran wrap® [polyvinylidene chloride] and was sonicated in a 35 KHz Elma Transsonic T-460 bath for 8 h. Thereafter, the mixture was diluted with water (15 mL) and extracted with hexane–ether (5 : 1, 20 mL). The organic phase was dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel (hexane–ether–$CHCl_3$, 4 : 1 : 1) to give **11c** (320 mg, 87%) as a colorless oil. IR (neat): ν 2980, 2870, 1719, 1606, 1490, 1462, 1367, 1270, 1179, 1108, 1023, 772 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.34 (t, 3H, CH_3, ^3J 7.0 Hz), 1.39 (t, 3H, CH_3, ^3J 7.0 Hz), 2.10 (d, 3H, CH_3, ^4J 1.6 Hz), 3.89 (s, 3H, OCH_3), 4.29 (q, 2H, ^3J 7.0 Hz), 4.40 (q, 2H, ^3J 7.0 Hz), 7.01 (d, 1H, ^3J 8.6 Hz), 7.53–7.57 (m, 2H), 7.61 (d, 2H, ^3J 8.4 Hz), 7.84 (q, 1H, ^4J 1.6 Hz), 8.11 (d, 2H, ^3J 8.4 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.34 (2C), 22.64, 55.69, 60.83, 60.94, 110.95, 125.47, 126.48, 128.44 (2C), 128.84, 129.01, 129.42, 130.13 (2C), 132.01, 134.31, 144.80, 157.69, 166.50, 168.47. MS (70 eV) m/z (%) 368 (M^+, 100), 337 (M^+–CH_3O, 33), 309 (M^+–C_2H_4–CH_3O, 64). HRMS (Found): 368.1622. Calc. for $C_{22}H_{24}O_5$: 368.1624.

(*E*)-Ethyl 3-(1″-ethoxycarbonyl-4′,4″-biphenyl)acrylate (11a). A mixture of **1d** (610 mg, 2.2 mmol), **2b** (660 mg, 4.4 mmol), **10a** (2.36 g, 5.5 mmol), $Pd(OAc_2)$ (30 mg, 0.13 mmol) and $Pd(PPh_3)_4$ (12 mg, 1×10^{-2} mmol) in hexane–ether (5 mL, 10 : 1 v/v) and 1.5 M aq. Na_2CO_3 (10 mL) was sonoirradiated for 5 h to give **11a** (606 mg, 85%). *E*-**11a**: colorless oil. IR (KBr) ν 2974, 1706, 1634, 1371, 1309, 1275, 1216, 1179, 1105, 993, 831, 773 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.3 Hz, CH_3), 1.42 (t, 3H, ^3J 7.3 Hz, CH_3), 4.28 (q, 2H, ^3J 7.3 Hz, OCH_2), 4.41 (q, 2H, ^3J 7.3 Hz, OCH_2), 6.49 (d, 1H, ^3J 15.9 Hz), 7.60–7.72 (m, 6H), 7.73 (d, 1H, ^3J 15.9 Hz), 8.12 (d, 2H, ^3J 8.4 Hz). MS (FAB, 3-nitrobenzyl alcohol) m/z (%) 325 (MH^+, 48). HRMS (Found): 325.1438. Calc. for $C_{20}H_{21}O_4$: 325.1440 (MH^+, FAB).

Ethyl 3-(1″-ethoxycarbonyl-3′,4″-biphenyl)acrylate (11b). A mixture of **1d** (610 mg, 2.2 mmol), **2c** (660 mg, 4.4 mmol), **10a** (2.36 g, 5.5 mmol), $Pd(OAc_2)$ (30 mg, 0.13 mmol) and $Pd(PPh_3)_4$ (12 mg, 1×10^{-2} mmol) in hexane–ether (5 mL, 10 : 1 v/v) and 1.5 M aq. Na_2CO_3 (10 mL) was sonoirradiated for 5.5 h to give **11b** (712 mg, quant). *E*-**11b**: pale yellow oil. IR (neat) ν 2980, 2902, 1706, 1639, 1609, 1476, 1445, 1398, 1367, 1271, 1173, 1105, 1034, 982 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.0 Hz, CH_3), 1.42 (t, 3H, ^3J 7.0 Hz, CH_3), 4.28 (q, 2H, ^3J 7.3 Hz, OCH_2), 4.44 (q, 2H, ^3J 7.0 Hz, OCH_2), 6.52 (d, 1H, ^3J 15.9 Hz), 7.44–7.78 (m, 6H), 7.76 (d, 1H, ^3J 15.9 Hz), 8.13 (d, 2H, ^3J 8.4 Hz). MS (FAB, 3-nitrobenzyl alcohol) m/z (%) 325 (MH^+, 35). HRMS (Found): 325.1441. Calc. for $C_{20}H_{21}O_4$: 325.1440 (MH^+, FAB).

Ethyl 3-[3′-(thien-2″-yl)phenyl]acrylate (11d). A mixture of **1a** (360 mg, 2.2 mmol), **2b** (660 mg, 4.4 mmol), **10a** (2.36 g, 5.5 mmol), $Pd(OAc_2)$ (30 mg, 0.13 mmol) and $Pd(PPh_3)_4$ (12 mg, 1×10^{-2} mmol) in hexane–ether (5 mL, 10 : 1 v/v) and 1.5 M aq. Na_2CO_3 (10 mL) was sonoirradiated for 5 h to give **11d** (567 mg, quant). *E*-**11d**: pale yellow oil. IR (neat) ν 3062, 2980, 2936, 1900, 1712, 1634 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.35 (t, 3H, ^3J 7.3 Hz, CH_3), 4.28 (q, 2H, ^3J 7.3 Hz, OCH_2), 6.49 (d, 1H, ^3J 15.9 Hz), 7.09 (dd, 1H, ^3J 5.1 Hz, J 3.5 Hz), 7.32 (dd, 1H, ^3J 5.1 Hz, ^4J 1.2 Hz), 7.34 (dd, 1H, ^3J 3.5 Hz, ^4J 1.2 Hz), 7.37–7.62 (m, 3H), 7.71 (d, 1H, ^3J 15.9 Hz), 7.74 (s, 1H). MS (FAB, 3-nitrobenzyl alcohol) m/z 259 (MH^+, 63). HRMS (Found) 259.0790. Calc. for $C_{15}H_{15}O_2S$: 259.0793 (MH^+, FAB).

Ethyl 3-(*p*-trifluoro-4′,4″-biphenyl)acrylate (11e). A mixture of **1f** (600 mg, 2.2 mmol), **2b** (660 mg, 4.4 mmol), **10a** (2.36 g, 5.5 mmol), $Pd(OAc_2)$ (30 mg, 0.13 mmol) and $Pd(PPh_3)_4$ (12 mg, 1×10^{-2} mol) in hexane–ether (5 mL, 10 : 1 v/v) and 1.5 M aq. Na_2CO_3 (10 mL) was sonoirradiated for 5 h to give **11e** (420 mg, 60%). *E*-**11e**: IR (KBr): ν 2986, 1706, 1635, 1614, 1326, 1175, 1118, 1069, 997, 822 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$) δ 1.31 (t, 3H, ^3J 7.3 Hz), 4.29 (q, 2H, ^3J 7.3 Hz), 6.48 (d, 1H, ^3J 15.9 Hz), 7.62 (s, 4H), 7.71 (s, 4H), 7.73 (d, 1H, ^3J 15.9 Hz). ^{13}C NMR (99.45 MHz, $CDCl_3$) δ 14.32, 60.60, 118.83, 125.85 (2C), 125.90 ($^2J_{C-F}$ 12 Hz) 127.32 (2C), 127.71 (2C), 128.65 (2C), 129.85 ($^1J_{C-F}$ 135 Hz), 129.99, 134.37, 141.35, 143.69, 166.87. MS (70 eV) m/z (%) 320 (M^+, 96), 275 (100), 248 (34), 178 (36). HRMS (Found): 320.1206. Calc. for $C_{18}H_{15}O_2F_3$: 320.1024.

References

1 O. I. Kolodiazhnyi, *Phosphorus Ylides – Chemistry and Application in Organic Synthesis*, Wiley-VCH, Weinheim, 1999.
2 T. Thiemann, M. Watanabe, Y. Tanaka and S. Mataka, *New J. Chem.*, 2004, **28**, 578.
3 (*a*) T. Thiemann, K. Umeno, D. Ohira, E. Inohae, T. Sawada and S. Mataka, *New J. Chem.*, 1999, **23**, 1067; (*b*) T. Thiemann, K. Umeno, E. Inohae and S. Mataka, *Rep. Inst. Adv. Mater. Study, Kyushu Univ.*, 2000, **14**, 17; (*c*) T. Thiemann, K. Umeno, E. Inohae and S. Mataka, *Chem. Abstr.*, 2000, **133**; (*d*) T. Thiemann, K. Umeno, J. Wang, K. Arima, M. Watanabe, Y. Tabuchi, Y. Tanaka, H. Gorohmaru and S. Mataka, *J. Chem. Soc., Perkin Trans. 1*, 2002, 2090.
4 For a one-pot Wittig olefination, Diels–Alder reaction, see: T. Thiemann, D. Ohira, Y. Q. Li, T. Sawada, S. Mataka, K. Rauch, M. Noltemeyer and A. de Meijere, *J. Chem. Soc., Perkin Trans. 1*, 2000, 2968.
5 For the use of benzoic acid in Wittig olefination reactions with stabilized phosphoranes, see: (*a*) C. Ruechardt, S. Eichler and P. Panse, *Angew. Chem.*, 1963, **75**, 858 (*Angew. Chem., Int. Ed. Engl.*, 1963, **2**, 619); (*b*) H. J. Bestmann and J. Lienert, *Chem.-Ztg.*, 1970, **94**, 487.
6 S. Kim, J. Yang and F. DiNinno, *Tetrahedron Lett.*, 1999, **40**, 2909.
7 (*a*) M. Watanabe, G. Ribeiro Morais, S. Mataka, K. Ideta and T. Thiemann, *Z. Naturforsch., B: Chem. Sci.*, 2005, **60**, 909, for

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Wittig–Horner olefination reactions see also: ; (*b*) A. Fuentes, J. M. Marinas and J. V. Sinisterra, *Tetrahedron Lett*., 1987, **28**, 2951; (*c*) J. V. Sinisterra, A. Fuentes and J. M. Marinas, *J. Org. Chem*., 1987, **52**, 3875.

8 For Suzuki cross-coupling and homocoupling reactions under ultrasound, see: G. Cravotto, G. Palmisano, S. Tollari, G. M. Nano and A. Penoni, *9th Meeting of the European Society of Sonochemistry, Badajoz 2004*, OC-34, p. 107 (homocoupling); T. Thiemann, *9th Meeting of the European Society of Sonochemistry, Badajoz 2004*, IL-8, Abstract Book, p. 31 (cross-coupling); V. Polackova, M. Hut'ka and S. Toma, *9th Meeting of the European Society of Sonochemistry, Badajoz, 2004*, P-38, Abstract Book, p. 197 (cross-coupling) and ref. 9.

9 (*a*) G. Cravotto, M. Beggiato, A. Penoni, G. Palmisano, S. Tollari, J. M. Leveque and W. Bonrath, *Tetrahedron Lett*., 2005, **46**, 2267; (*b*) V. Polackova, M. Hut'ka and S. Toma, *Ultrason. Sonochem*., 2005, **12**, 99.

10 Suzuki coupling under ultrasound in ionic liquids has also been reported: R. Rajagopal, D. V. Jarikote and K. V. Srinivasan, *Chem. Commun*., 2002, 616.

11 Wm. J. Considine, *J. Org. Chem*., 1962, **27**, 647.

12 F. Ramirez and S. Dershowitz, *J. Org. Chem*., 1957, **22**, 41.

13 S. Trippett and D. M. Walker, *J. Chem. Soc*., 1959, 3874.

14 R. F. Hudson and D. A. Chopard, *Helv. Chim. Acta*, 1963, **46**, 2178.

15 (*a*) H. R. Howard and B. T. O'Neill, PCT Int. Appl. WO 9413663, Pfizer Inc., USA, 1994; (*b*) S. J. Warrelow, E. C. Boyd and R. K. Alexander, PCT Int. Appl. WO 9535283, Celltech Therapeutics Ltd., UK, 1995.

16 For Suzuki cross-coupling reactions with halopyridines, see: H. Chaumeil, C. Le Drian and A. Defoin, *Synthesis*, 2002, 757.

17 S. Cacchi, D. Misiti and F. L. Torre, *Synthesis*, 1980, 243.

18 Autorenkollektiv, *Organikum*, VEB Deutsche Verlag der Wissenschaften, 1988, p. 655.

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