# Palladium-Catalyzed Cross-Coupling Reactions of Highly Hindered, Electron-Rich Phenol Triflates and Organostannanes

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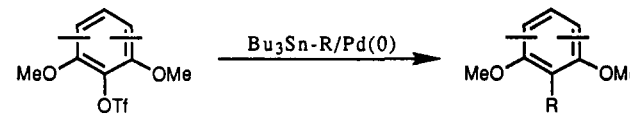
The palladium-catalyzed cross-coupling reaction of highly hindered, electron-rich phenol triflates and organostannanes (Stille reaction) has been studied in a systematic manner. The following are its salient features: (1) electron-rich phenol triflates require triphenylphosphine to undergo palladium-catalyzed cross-couplings; (2) in general, efficient reactions take place only when larger-than-usual amounts (10–15%) of palladium are employed. On the reagent side, alkyl- (methyl only), allyl-, vinyl- and alkinylstannanes undergo efficient cross-couplings with the title substrates. However, some limitations to this novel entry to 2-substituted resorcinols exist in regard to both substrates and reagents. Thus, conformationally rigid (hexasubstituted) aryl triflates behave poorly, demethylation being an important side reaction. Moreover, alkyl groups other than methyl cannot be introduced because $\beta$ elimination occurs more rapidly. The potentially powerful synthesis of hindered biaryls has also been studied briefly. In the present conditions, the reaction appears to be limited by the presence of ortho substituents on the arylstannane moiety.

The so called Stille reaction, i.e. the cross-coupling reaction of vinyl and aryl triflates with organostannanes, has already enjoyed extensive application in organic synthesis in spite of the very short period of time elapsed since its publication.[1] In particular, cross-couplings of aryl triflates have gained full credit as a powerful method for preparing functionalized aromatics not easy to synthesize by more classic approaches.[2]

Although numerous publications on this reaction have appear during the last few years,[3] to the best of our knowledge there has been no systematic study with hindered, electron-rich aryl triflates,[4] possibly due to their well-known reluctancy to undergo palladium-catalyzed reactions.[5] The only exception, coming from our laboratory, is the recent demonstration that palladium(0)-catalyzed reduction of hindered, electron-rich phenol triflates is a very efficient process which, on the mechanistic side, has been suggested to proceed through several reduction pathways.[6]

**Scheme I**




We became interested in preparing some highly substituted resorcinol derivatives (and closely related substances) due to their valuable pharmacological properties.[7] The straightforward plan devised for that purpose (Scheme I) called for the introduction of several R groups such as alkyl, vinyl, allyl, aryl, etc. in place of the existing OH of highly substituted 2,6-dimethoxyphenols. For the sake of establishing generality, other closely related substrates (2,6-disubstituted phenols) were also employed throughout our work.

Described herein is a full account of the scope and limitations of the Stille reaction as applied to these highly substituted phenols.[8] In outline, the main conclusion derived from this work is that Pd(0)-catalyzed cross-couplings of hindered phenol triflates with organostannanes work well in most cases (except for hexasubstituted benzenes), thus providing a unique entrance to aromatic polyketides from phenols having a basic shikimic acid substitution pattern, as well as from related substances. A preliminary study of its application to the synthesis of

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(2) (a) Echavarren, A. M.; Stille, J. K. *J. Am. Chem. Soc.* **1987**, *109*, 5478. (b) Echavarren, A. M.; Stille, J. K. *J. Am. Chem. Soc.* **1988**, *110*, 1557. (c) For the use of aryl fluorosulfonates as an alternative of aryl triflates, see: Roth, G. P.; Fuller, C. E. *J. Org. Chem.* **1991**, *56*, 3493.

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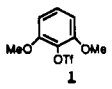
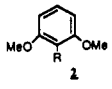
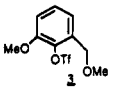
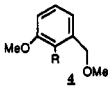
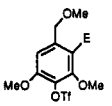
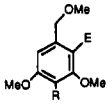
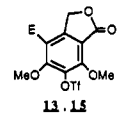
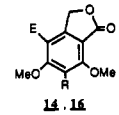
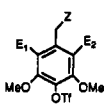
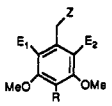
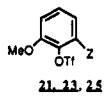
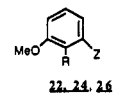
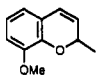
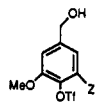
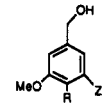
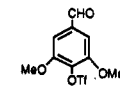
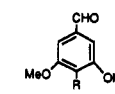
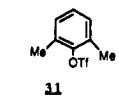
(7) For some recent syntheses of substituted resorcinols, see: Azzena, U.; Cossu, S.; Denurra, T.; Melloni, G.; Piroddi, A. M. *Synthesis* **1990**, 313. Azzena, U.; Denurra, T.; Melloni, G.; Piroddi, A. M. *J. Org. Chem.* **1990**, *55*, 5386. Azzena, U.; Cossu, S.; Denurra, T.; Melloni, G.; Piroddi, A. M. *Tetrahedron Lett.* **1989**, *30*, 1689. Kanakam, C. C.; Mani, N. S.; Ramanathan, H.; Subba Rao, G. S. R. *J. Chem. Soc., Perkin Trans. 1* **1989**, 1907. Danheiser, R. L.; Nishida, A.; Savariar, S.; Trova, M. P. *Tetrahedron Lett.* **1988**, *29*, 4917. Azzena, U.; Denurra, T.; Melloni, G.; Rassu, G. *J. Chem. Soc., Chem. Commun.* **1987**, 1549. Danheiser, R. L.; Gee, S. K.; Perez, J. J. *J. Am. Chem. Soc.* **1986**, *108*, 806. Bailey, K. *Can. J. Chem.* **1974**, *52*, 2136.

(8) A preliminary communication has appeared in print. See: Martorell, G.; García-Raso, A.; Saá, J. M. *Tetrahedron Lett.* **1990**, *31*, 2357.

0022-3263/92/1957-0678$03.00/0 

**Table I**

| entry | substrate | organostannane | product (yield,[a] %) |
|---|---|---|---|
| |  1 | $RSnBu_3$ |  2 |
| 1 | 1 | R= Me[b] | 2a (92%) |
| 2 | 1 | R= Ph | 2b (74%) |
| 3 | 1 | R= $CH_2CH=CH_2$ | 2c (84%) |
| 4 | 1 | R= $CH=CH_2$ | 2d (85%) |
| 5 | 1 | R= C≡C-Ph | 2e (50%) |
| 6 | 1 | R= n-Bu | 2f (0%)[c] |
| 7 | 1 | R= o-MeO-$C_6H_4$ | 2g (33%) |
| |  3 | $RSnBu_3$ |  4 |
| 8 | 3 | R= Me[b] | 4a (96%) |
| 9 | 3 | R= Ph | 4b (79%) |
| 10 | 3 | R= $CH_2CH=CH_2$ | 4c (98%) |
| 11 | 3 | R= $CH=CH_2$ | 4d (90%) |
| 12 | 3 | R= C≡C-Ph | 4e (56%) |
| 13 | 3 | R= o-MeO-$C_6H_4$ | 4g (46%) |
| |  5, 7, 9, 11 | $RSnBu_3$ |  6, 8, 10, 12 |
| 14 | 5 E= Cl | R= $CH_2CH=CH_2$ | 6c E= Cl; R= $CH_2CH=CH_2$ (63%) |
| 15 | 7 E= Br | R= $CH_2CH=CH_2$ | 8c E= $CH_2CH=CH_2$; R= OTf (92%) |
| 16 | 7 E= Br | R= $CH_2CH=CH_2$ | 8cc E= R= $CH_2CH=CH_2$ (67%) |
| 17 | 9 E= SMe | R= Me | 10a E= SMe; R= Me (58%) |
| 18 | 11 E= COOEt | R= $CH_2CH=CH_2$ | 12c E= COOEt; R= $CH_2CH=CH_2$ (68%) |
| |  13, 15 | $RSnBu_3$ |  14, 16 |
| 19 | 13 E= H | R= $CH_2CH=CH_2$ | 14c E= H; R= $CH_2CH=CH_2$ (34%) |
| 20 | 15 E= Cl | R= $CH_2CH=CH_2$ | 16c E= Cl; R= $CH_2CH=CH_2$ (0%) |
| |  17, 19 | $RSnBu_3$ |  18, 20 |
| 21 | 17 $E_1$= $E_2$= Cl; Z= OMe | R= $CH_2CH=CH_2$ | 18c $E_1$= $E_2$= Cl; Z= OMe; R= $CH_2CH=CH_2$ (28%) |
| 22 | 19 $E_1$= Cl; $E_2$= COOEt; Z= OMe | R= $CH_2CH=CH_2$ | 20c $E_1$= Cl; E= COOEt; Z= OMe; R= $CH_2CH=CH_2$ (0%) |
| |  21, 23, 25 | |  22, 24, 26 |
| 23 | 21 Z= COOMe | R= $CH_2CH=CH_2$ | 22c Z= COOMe; R= $CH_2CH=CH_2$ (97%) |
| 24 | 21 Z= COOMe | R= Ph | 22b Z= COOMe; R= Ph (87%) |
| 25 | 21 Z= COOMe | R= o-MeO-$C_6H_4$ | 22g Z= COOMe; R= o-MeO-$C_6H_4$ (0%) |
| 26 | 23 Z= CHO | R= $CH_2CH=CH_2$ | 24c  (34%) |
| 27 | 23 Z= CHO | R= $CH_2CH=CH_2$ | 24cc Z= $CH(OH)CH_2CH=CH_2$; R= $CH_2CH=CH_2$ (55%) |
| 28 | 25 Z= $NO_2$ | R= $CH_2CH=CH_2$ | 26c Z=$NO_2$; R=$CH_2CH=CH_2$ (0%) |
| |  27 | |  |
| 29 | 27 Z= Br | R= $CH_2CH=CH_2$ | 28c Z= $CH_2CH=CH_2$; R= OTf (67%) |
| 30 | 27 Z= Br | R= $CH_2CH=CH_2$ | 28cc Z= R= $CH_2CH=CH_2$ (41%) |
| |  29 | |  |
| 31 | 29 | R= $CH_2CH=CH_2$ | 30c R= $CH_2CH=CH_2$ (78%) |
| |  31 | |  |
| 32 | 31 | R= $CH_2CH=CH_2$ | 32c R= $CH_2CH=CH_2$ (62%) |
| 33 | 31 | R= o-MeO-$C_6H_4$ | 32g R= o-MeO-$C_6H_4$ (57%) |

[a] Isolated yields. [b] $Me_4Sn$ was used. [c] An 86% yield of deoxygenated material (R = H) was obtained.

hindered biaryls is also included.

## Results and Discussion

**Reaction Conditions.** The salient features of the present study are summarized in Table I. Aryl triflates were synthesized uneventfully (see the Experimental Section for details) from the corresponding phenols,[9] which were available either from commercial sources or by straightforward transformations. In particular, compounds **9**, **11**, **13**, **15**, and **19** were obtained following our recently developed methodology for the direct lithiation of phenols.[10]

After some experimentation we found that the best catalytic system for the conversion **1** → **2** involved the use of $PdCl_2(PPh_3)_2$ (0.1–0.15 mol)/$PPh_3$ (0.4 mol)/LiCl (8 mol) in refluxing DMF.[11] Unless indicated otherwise these optimized conditions were used throughout.

Two remarkable differences are evident in comparison with the reported conditions of Stille and Echavarren.[2a] First is that triphenylphosphine[12] appears to play a key role (in its absence palladium black precipitates after a few minutes) with electron-rich substrates such as **1**, whereas like Stille's examples those educts featuring either a coordinating side arm (as in **3**) or an electron-withdrawing group (as in **21** and **29**) undergo cross-couplings more efficiently and in shorter reaction times without added triphenylphosphine. Secondly palladium catalyst is needed for reactions of **1** and **3** to work efficiently. Thus, as a rule, reactions with electron-rich triflates such as **1** and **3** work best with 10–15 mol % palladium whereas aryl triflates having electron-withdrawing groups such as **21** and **29** (Table I, entries 23, 24, and 31) react efficiently with a reduced amount of palladium (3–6 mol %), as recently reported by Robl.[13]

(9) Stang, P. J.; Hanack, M.; Subramanian, L. R. *Synthesis* **1982**, 85.
(10) Saá, J. M.; Llobera, A.; García-Raso, A.; Costa, A.; Deyà, P. M. *J. Org. Chem.* **1988**, *53*, 4263. Saá, J. M.; Morey, J.; Costa, A. *Tetrahedron Lett.* **1986**, *27*, 5125. Morey, J.; Costa, A.; Deyà, P. M.; Suñer, G.; Saá, J. M. *J. Org. Chem.* **1990**, *55*, 3902.
(11) The solvent (DMF) has been shown to play a significant role in the Pd-catalyzed coupling between hindered iodonucleosides and acetylenes. See: Robins, M. J.; Vinayak, R. S.; Wood, S. G. *Tetrahedron Lett.* **1990**, *26*, 3731.
(12) In a brief comparison study with different phosphine ligands it was found that triphenylphosphine worked much better than biphosphines such as 1-1'-bis(diphenylphosphino)ferrocene (dppf), (diphenylphosphino)propane (dppp), or (diphenylphosphino)ethane (dppe), except for the coupling of alkinylstannanes (see text).
(13) Robl, J. A. *Tetrahedron Lett.* **1990**, *31*, 3421.

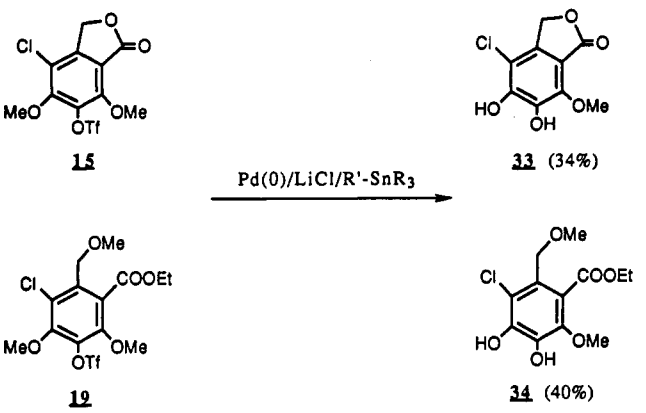
**Reaction Scope.** Allylic isomerization has been reported to occur in the cross-coupling reactions of tributyl(allyl)stannane with the triflate derivative of 4-hydroxyacetophenone and with 4-bromoacetophenone.[2a] In all cases, our electron-rich, highly encumbered educts underwent clean cross-couplings with tributyl(allyl)stannane, yielding only the allyl-substituted aromatic (Table I, entries 3, 10, 14, 15, 16, 18–23, and 26–32). No allyl to propenyl isomerization has ever been observed during the present study.[14a] If a Pd(0)-catalyzed reaction is responsible for the observed isomerization,[2a] as initially suggested by Heck et al.,[14b] highly encumbered allyl-substituted aromatics such as ours may not undergo the necessary complex formation with Pd(0) prior to the isomerization steps (presumably involving a $\eta^3$-allylpalladium intermediate), therefore being stable under these conditions. This result might be of considerable synthetic value for the introduction of large isoprenyl groups, provided that allyl rearrangement does not take place.[2a,15]

Careful examination of the results on Table I also reveals additional interesting features of likely synthetic value. Thus, according to expectation,[16] even the sensitive aldehyde group survives the reaction conditions above (entry 31). Interestingly, attack on the carbonyl group can be observed for the case of **23**. Actually, chromene **24c** can be isolated as the major compound (entry 26, 34%) when working with limited amounts (1.2 equiv) of stannane[17] in the absence of triphenylphosphine. The presence of triphenylphosphine facilitates cross-coupling on the triflate group as shown by the formation of doubly allylated **24cc** (55% yield, entry 27) from excess stannane under the otherwise general cross-coupling conditions.

The chemoselectivity of the cross-coupling reactions, followed the established order of reactivity[2a] (OTf ≥ Br > Cl) in some cases (OTf vs Cl, entry 14, **5** → **6**) but did not in some others (Br vs. OTf, entries 15 and 16, **7** → **8**).[18] The former result (Table I, entry 15, **7** → **8c**) was obtained only by working under controlled conditions, i.e., with a reduced amount (6 mol %) of palladium catalyst in the absence of both triphenylphosphine and LiCl, thusly impeding the reaction at the triflate group (which requires triphenylphosphine). Lower amounts of palladium catalyst (1.5% molar), in the absence of triphenylphosphine, afforded poorer results (67% yield; not shown in Table I) while standard conditions led to doubly allylated **8cc** (Table I, entry 16) as the major compound (67%). Unlike with Stille's unhindered triflates, chemoselectivity of our hindered compounds was not significantly modified when the catalyst was changed to $Pd(PPh_3)_4$.[2a] This can be easily rationalized by considering that, in solution, $Pd(PPh_3)_4$ is in equilibrium with $Pd(PPh_3)_2$ and triphenylphosphine which, as mentioned above, is a necessary requirement for the cross-couplings of highly encumbered electron-rich triflates (but not for regular ones) to take place.

Chemoselective cross-coupling (Br vs OTf) was also achieved in the case of bromo triflate **27** (entries 29, 30)

**Scheme II**




although, again, controlled conditions were needed. Thus, when using a catalytic amount (3 mol %) of palladium in the absence of added triphenylphosphine and lithium chloride, the regioselective cross-coupling **27** → **28c** took place, although a significant amount of starting material remained unreacted, as judged by GC/MS analysis. Interestingly, even when the reaction was carried out with only 3 mol % Pd, in the presence of triphenylphosphine (no lithium chloride added), during the same period of time (2 h), trace amounts of doubly allylated material, together with the major product **28c** (67%, entry 29) were detected by GC/MS. Higher amounts of catalyst (12 mol %), of course, led to a significant increase in the doubly allylated material **28cc** (Table I, entry 30).

As judged from the data shown in Table I, transfer of methyl, vinyl, or allyl groups from tin occurs uneventfully, except for the case of *o*-nitro triflate **25** which gave a complex mixture of products not further examined in detail.

However, all attempts at introducing alkyl groups other than methyl on triflate **1** met with complete failure. The reduced arene was the only isolable material (Table I, entry 6). Presumably, this behavior arises in hindered triflates because $\beta$ elimination ensues rapidly on the trans arylalkylpalladium(II) species, thus advantageously competing with the seemingly slower reductive elimination step which takes place on the corresponding cis species.

Only low to moderate yields were achieved for the introduction of acetylene moieties, but significant improvement was noticed when using dppf (1,1′-bis(diphenylphosphino)ferrocene) instead of triphenylphosphine (entries 5, 12). For the sake of comparison, though, it is worth mentioning that all attempts at reacting triflates **1** and **3** with phenylacetylene under standard Heck reaction conditions were fruitless, the starting material being recovered unchanged. This observation is in accordance with the recently reported reluctancy of highly congested bromo aromatics to react with acetylenes, although the corresponding iodo derivatives, being more reactive, did undergo the reaction in good yield.[19]

The degree of substitution on the aromatic ring causes some limitations on the scope of the reaction. Thus, whereas all pentasubstituted aryl triflates assayed by us reacted satisfactorily in spite of the severe crowding of the functional groups present, a number of serious inconveniences appeared during our attempted cross-couplings with hexasubstituted aryl triflates **15**, **17**, and **19**, possibly be-

(14) (a) Kosugi, M.; Sasazawa, K.; Shimizu, Y.; Migita, T. *Chem. Lett.* **1977**, 301. (b) Heck, R. F. *J. Am. Chem. Soc.* **1968**, *90*, 5531.

(15) Isomerization, see ref 14b. Allyl rearrangement, see: Trost, B. M.; Keinan, E. *Tetrahedron Lett.* **1980**, *21*, 2595. Godschalx, J.; Stille, J. K. *Tetrahedron Lett.* **1980**, *21*, 2599.

(16) Cuevas, J.-C.; Patil, P.; Snieckus, V. *Tetrahedron Lett.* **1989**, *30*, 5841. Okamoto, Y.; Yoshioka, K.; Yamana, T.; Mori, H. *J. Organomet. Chem.* **1989**, *369*, 285. See also ref 2a.

(17) Pereyre, M.; Quintard J.-P.; Rahm, A. *Tin in Organic Synthesis*; Butterworths: New York, 1987.

(18) Examples where the inverse regioselectivity has been observed are known. See, ref 19b and Holt, D. A.; Levy, M. A.; Ladd, D. L.; Oh, H.-J.; Erb, J. M.; Heaslip, J. I.; Brandt, M.; Metcalf, B. W. *J. Med. Chem.* **1990**, *33*, 937.

(19) (a) See refs 4d, 4f, and 4g. (b) For the successful reaction of hindered electron-rich bromides, see: Krolski, M. E.; Renaldo, A. F.; Rudisill, D. E.; Stille, J. K. *J. Org. Chem.* **1988**, *53*, 1170. Friesen, R. W.; Sturino, C. F. *J. Org. Chem.* **1990**, *55*, 2752 and 5808. Friesen, R. W.; Daljeet, A. K. *Tetrahedron Lett.* **1990**, *43*, 6133. See also ref 4e.

cause of their conformationally restricted structures.[20] Thus, when lactone **15** was submitted to reaction with tributyl(allyl)stannane, no trace of the desired cross-coupled product **16c** was detected. Instead a diphenolic compound was isolated in 34% yield from the complex reaction mixture.[21] Structure **33** (para demethylation) has been tentatively assigned to it on the basis of its spectroscopic data.[22] Ester **19** behaved analogously, i.e., the major product isolated (40% yield) from the Pd(0)-catalyzed cross-coupling reaction with tetramethylstannane was a diphenolic ester to which structure **34** (para demethylation) has been tentatively assigned (Scheme II). Being a less crowded molecule, triflate **17** yielded the expected product **18c**, though only in poor yield (Table I, entry 21).

Although it is clearly premature to advance any detailed generalized mechanism for these cross-coupling reactions, the oxidative addition appears to be the rate-determining step for our electron-rich, highly encumbered aryl triflates. This is supported by the following two observations: (1) large amounts of catalyst (12 mol %, typically) are required for type 1 educts[23] and (2) substrates having electron-withdrawing groups such as **21** and **29** undergo exceedingly fast reactions even when working with a limited amount of palladium catalyst.[24] On the other hand, the specific requirement of added triphenylphosphine (or the presence of a coordinating side arm) for some reactions to occur is interpreted as an indication of the reductive elimination being of the associative type,[25] a mechanism that could produce some release of steric strain.

We have also spent some time in defining the scope and limitations of the important biaryl synthesis.[26] Due to the availability of phenolic compounds (when compared with aryl iodides or bromides), it was clear to us that such a methodology would be of high value for preparative chemists. Although only a limited number of reactions have been carried out (entries 2, 7, 9, 13, 24, 25, and 33, unoptimized) a clear-cut (strong) dependance on the steric hindrance of the organometallic component can be assessed.[27] Thus, whereas compounds **1**, **3**, or **21** reacted uneventfully with tributyl(phenyl)stannane giving rise to the expected biaryls in good yields (Table I, entries 2, 9, and 24), the analogous reaction of **1**, **3**, **21**, or **31** (entries 7, 13, 25, and 33) with tributyl(*o*-methoxyphenyl)stannane, in general, afforded the corresponding biaryls in lower yields. In particular, it is worth emphasizing the difficulties found in preparing **2g** and **22g**. Actually, a 33% isolated yield of biaryl **2g** could be realized only by working under very stringent conditions (145 °C, 24 h) and using a larger amount of palladium catalyst (20%). Biarylic ester **22g**, on the other hand, could only be detected by GC/MS in the complex reaction mixture obtained under a variety of reaction conditions.

Overall, the synthetic strategy leading to heavy substituted resorcinols and related substances (Scheme I) is a powerful one, especially when combined with our recently developed phenol lithiation methodology.[10] However, limitations exist both in substrates and reactants of the Pd(0)-catalyzed cross-coupling reaction. Thus, as illustrated above, the reaction of hexasubstituted, conformationally rigid aryl triflates does not work properly. In addition, the introduction of large alkyl chains is also an unsolved problem. Finally, the Pd(0)-catalyzed synthesis of hindered biaryls is limited by the presence of ortho substituents on the arylstannane moiety.

## Experimental Section

**General Methods.** All melting points are uncorrected and were taken on a capillary melting point apparatus. The boiling points given refer to those observed on bulb-to-bulb distillation (Büchi GKR-50 apparatus). Proton NMR spectra were obtained on a Varian FT-80A and Bruker AMX 300 spectrometer in $CDCl_3$ (unless otherwise noted) with $Me_4Si$ as internal standard. Electron impact mass spectra were recorded on a Hewlett-Packard 5988A GC/MS operating at 70 eV ionizing energy. High-resolution mass spectra were obtained in a Kratos MS-50 instrument (U. de Santiago de Compostela) and a VG Micromass ZAB-2F model (U. de La Laguna). Infrared spectra were recorded on a Hitachi 260-10 infrared spectrophotometer. Elemental analyses were obtained at the Servei de Microanàlisi del CSIC (Barcelona). Column chromatography was performed on silica gel Merck (Kieselgel 60). Commercial dry DMF, phenols, and stannanes were used as received from Aldrich. Tributyl(*o*-methoxyphenyl)stannane was prepared as reported.[29] Dry LiCl was prepared by heating at 100 °C (0.1 mmHg) for 6 h. The purity of all title compounds was judged to be >95% by $^{13}C$ and $^1H$ NMR spectral determinations.

**Aryl Triflates.** 2,6-Dimethoxyphenyl trifluoromethanesulfonate (**1**), 2,6-dimethoxy-4-(methoxymethyl)-3-(methylthio)phenyl trifluoromethanesulfonate (**9**) and 1,3-dihydro-5,7-dimethoxy-6-[(trifluoromethanesulfonyl)oxy]isobenzofuran-1-one (**13**) were prepared as previously reported.[6a] The following triflates have been prepared analogously from the corresponding phenols, unless otherwise indicated.

**2-Methoxy-6-(methoxymethyl)phenyl trifluoromethanesulfonate (3)** was prepared from the corresponding phenol[10] in 70% yield: oil; bp 130–135 °C (0.25 mmHg); IR (film) $\nu$ 1615, 1580, 1480, 1420, 1305, 1285, 1220, 1140, 1075, 885, 780, 760 $cm^{-1}$; $^1H$ NMR $\delta$ 7.30 (t, 1 H, $J$ = 7.7 Hz), 7.06 (d, 1 H, $J$ = 7.7 Hz), 6.95 (d, 1 H, $J$ = 7.7 Hz), 4.52 (s, 2 H), 3.87 (s, 3 H), 3.40 (s, 3 H) ppm; $^{13}C$ NMR $\delta$ 150.96, 136.51, 132.55, 128.41, 120.83, 118.59 (q, $J$ = 320 Hz), 112.10, 68.52, 58.09, 55.70 ppm; EIMS $m/e$ (%) 300 ($M^+$, 27), 167 (100), 139 (30), 137 (26), 136 (16), 124 (84), 109 (21), 108 (29), 107 (48), 106 (22), 96 (34), 81 (35), 77 (58). Anal. Calcd for $C_{10}H_{11}F_3O_5S$: C, 40.00; H, 3.67. Found: C, 39.99; H, 3.70.

**3-Chloro-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluoromethanesulfonate (5)** was synthesized from 3-chloro-2,6-dimethoxy-4-(methoxymethyl)phenol in 66% yield, itself prepared by straightforward monochlorination of 2,6-dimethoxy-4-(methoxymethyl)phenol:[10] clear oil; bp 165–70 °C (0.12 mmHg); IR (film) $\nu$ 1595, 1475, 1465, 1430–1400, 1380, 1340, 1250–1190, 1150–1100, 980, 900, 790, 750 $cm^{-1}$; $^1H$ NMR $\delta$ 6.98 (s, 1 H), 4.51 (s, 2 H), 3.91 (s, 6 H), 3.49 (s, 3 H) ppm; $^{13}C$ NMR $\delta$ 150.82, 149.29, 137.60, 131.65, 118.52 (q, $J$ = 320.4 Hz), 117.74, 106.83, 70.95, 61.27, 58.61, 56.23 ppm; EIMS $m/e$ (%) 364 ($M^+$, 35), 233 (23), 231 (71), 205 (32), 203 (100), 188 (15), 173 (18), 172 (21), 168 (75), 153 (47), 145 (15). Anal. Calcd for $C_{11}H_{12}ClF_3O_6S$: C, 36.21; H, 3.29. Found: C, 36.39; H, 3.19.

(20) Tidwell, T. T. *Tetrahedron* **1978**, *34*, 1855. For some recent synthetic approaches to highly substituted benzene derivatives, see: Danheiser, R. L.; Nishide, A.; Savarian, S.; Trova, M. P. *J. Org. Chem.* **1988**, *39*, 4917 and references cited therein.

(21) A related t-BOC clevage has been reported. See ref 4a.

(22) Bernard, A.; Ghiani, M. R.; Piras, P. P.; Rivoldini, A. *Synthesis* **1989**, 287 and references cited therein.

(23) The need for large amounts of Pd(0) had already been noted for aryl bromide cross-couplings. See: McKean, D. R.; Parinello, G.; Renaldo, A. F.; Stille, J. K. *J. Org. Chem.* **1987**, *52*, 422.

(24) Milstein, D.; Stille, J. K. *J. Am. Chem. Soc.* **1979**, *101*, 4992. See also ref 5 and Fauvarque, J. F.; Pflüger, F. *J. Organomet. Chem.* **1981**, *208*, 419.

(25) Gillie, A.; Stille, J. K. *J. Am. Chem. Soc.* **1980**, *102*, 4933. See also Braterman, P. J.; Cross, R. J.; Young, G. B. *J. Chem. Soc.*, Dalton *Trans.* **1976**, 1306, 1310.

(26) For a recent, comprehensive review on the subject see: Bringmann, G.; Walter, R.; Weirich, R. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 977. See also: Huth, A.; Beetz, I.; Schumann, I. *Tetrahedron Lett.* **1989**, *21*, 6679. Fu, J.-M.; Snieckus, V. *Tetrahedron Lett.* **1990**, *31*, 1665 and references cited therein.

(27) Cross-couplings of aryl halides or triflates with hindered arylboronic acids, aryltin, or arylzinc compounds have been shown to be highly dependant on the steric hindrance of the organometallic component. See ref 24. See, however: Widdowson, D. A.; Zhang, Y.-Z. *Tetrahedron* **1986**, *42*, 2111.

(28) Aldrich Catalog 1990–1991, no. D13,720-0.

(29) Kozgrod, R. P.; Morgan, J.; Pinkey, J. T. *Austr. J. Chem.* **1985**, *38*, 1147.

**3-Bromo-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluoromethanesulfonate (7)** was synthesized from 3-bromo-2,6-dimethoxy-4-(methoxymethyl)phenol in 72% yield, itself prepared by straightforward monobromination of 2,6-dimethoxy-4-(methoxymethyl)phenol:[10] clear oil; bp 155–60 °C (0.15 mmHg); IR (film) $\nu$ 1590, 1470–1450, 1430–1400, 1220, 1190, 1140, 1110, 890, 760 cm$^{-1}$; $^1$H NMR $\delta$ 7.01 (s, 1 H), 4.48 (s, 2 H), 3.90 (s, 6 H), 3.50 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 151.54, 150.21, 139.10, 131.66, 118.55 (q, $J$ = 320.7 Hz), 107.39, 103.99, 73.37, 61.33, 58.75, 56.37 ppm; EIMS $m/e$ (%) 410 (M$^+$ + 2, 13), 408 (M$^+$, 14), 277 (27), 275 (26), 196 (24), 181 (13), 168 (100), 153 (41), 125 (11), 69 (17). Anal. Calcd for $C_{11}H_{12}BrF_3O_6S$: C, 32.27; H, 2.93. Found: C, 32.33; H, 2.89.

**3-(Carboxyethyl)-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluoromethanesulfonate (11)** was prepared in 68% from the corresponding hydroxy acid[10] as follows: dropwise addition of triflic anhydride (11 mmol) to a chilled (0 °C) methylene chloride solution (20 mL) of hydroxy acid (2.39 mmol), 2,4,6-trimethylpyridine (19 mmol), and absolute ethanol (7.17 mmol), followed by overnight stirring at room temperature. Standard workup yielded a crude ester as an oil that was dissolved in anhydrous methylene chloride (30 mL) and treated with 2,4,6-trimethylpyridine (9.6 mmol) and triflic anhydride (2.87 mmol) and then stirred overnight. Standard workup yielded 11 as a clear oil: bp 160–65 °C (0.2 mmHg); IR (film) $\nu$ 1720, 1600, 1420, 1270, 1210, 1140, 1110, 1020, 910, 840 cm$^{-1}$; $^1$H NMR $\delta$ 6.92 (s, 1 H), 4.50 (s, 2 H), 4.38 (q, 2 H, $J$ = 7.1 Hz), 3.92 (s, 3 H), 3.90 (s, 3 H), 3.40 (s, 3 H), 1.31 (t, 3 H, $J$ = 7.1 Hz) ppm; $^{13}$C NMR $\delta$ 165.18, 152.92, 151.07, 138.56, 130.81, 119.52, 118.34 (q, $J$ = 320 Hz), 106.93, 71.46, 62.04, 61.08, 58.00, 55.95, 13.56 ppm; EIMS $m/e$ (%) 402 (M$^+$, 1), 357 (5), 269 (23), 210 (10), 209 (100). Anal. Calcd for $C_{14}H_{17}F_3O_8S$: C, 41.79; H, 4.23. Found: C, 41.97; H, 4.09.

**4-Chloro-1,3-dihydro-5,7-dimethoxy-6-[(trifluoromethanesulfonyl)oxy]isobenzofuran-1-one (15)** was prepared from 5-chloro-3-hydroxy-2,4-dimethoxy-6-(methoxymethyl)benzoic acid: $^1$H NMR $\delta$ 5.65 (broad s, 1 H), 4.65 (s, 2 H), 3.92 (s, 6 H), 3.37 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 169.02, 145.21, 143.82, 143.33, 125.26, 123.79, 123.42, 68.19, 61.53, 60.50, 57.57 ppm; EIMS $m/e$ (%) 278 (M$^+$ + 2, 3), 276 (M$^+$, 9), 245 (18), 244 (14), 243 (46), 209 (62), 197 (14), 88 (10), 86 (66), 84 (100), itself obtained in 52% overall yield by monochlorination of the corresponding acid.[10] Application of the previously described two-step, one-pot procedure[6a] to this compound led to **15** as an oil: bp 175–180 °C (0.11 mmHg); IR (film) $\nu$ 1770, 1590, 1470, 1420, 1360, 1230–1210, 1130, 970, 940, 915, 795 cm$^{-1}$; $^1$H NMR $\delta$ 5.22 (s, 2 H), 4.31 (s, 3 H), 4.07 (s, 3 H) ppm; $^{13}$C NMR ($CDCl_3$ + acetone-$d_6$) $\delta$ 165.93, 154.02, 150.76, 146.35, 135.57, 118.24 (q, $J$ = 320 Hz), 115.00, 112.92, 67.61, 63.41, 61.74 ppm; EIMS $m/e$ (%) 378 (M$^+$ + 2, 4), 376 (M$^+$, 10), 245 (32), 243 (100), 215 (21), 213 (13), 187 (13), 185 (20), 69 (27). Anal. Calcd for $C_{11}H_8ClF_3O_7S$: C, 35.11; H, 2.13. Found: C, 35.18; H, 2.22.

**3,5-Dichloro-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluoromethanesulfonate (17)** was prepared in 63% from the corresponding phenol, itself obtained by straightforward chlorination (NCS) of 2,6-dimethoxy-4-(methoxymethyl)phenol.[10] Triflate **17** was obtained as a clear oil: bp 145–50 °C (0.2 mmHg); IR (film) $\nu$ 1595, 1460, 1420, 1400, 1210, 1140, 1100, 980, 920, 800, 750 cm$^{-1}$; $^1$H NMR $\delta$ 4.65 (s, 2 H), 3.87 (s, 6 H), 3.40 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 148.17, 137.42, 134.76, 126.31, 118.31 (q, $J$ = 321 Hz), 68.40, 61.25, 58.27 ppm; EIMS $m/e$ (%) 400 (M$^+$ + 2, 35), 398 (M$^+$, 47), 267 (31), 265 (30), 239 (41), 237 (73), 230 (19), 215 (19), 206 (17), 204 (41), 202 (100), 191 (15), 190 (15), 189 (35), 187 (93), 163 (16), 159 (20), 113 (16), 111 (20), 109 (35), 99 (16), 87 (22), 85 (30), 75 (18), 69 (66), 59 (16). Anal. Calcd for $C_{11}H_{11}Cl_2F_3O_6S$: C, 33.16; H, 2.76. Found: C, 33.20; H, 2.80.

**3-(Carboxyethyl)-5-chloro-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluoromethanesulfonate (19)** was prepared in 53% from the above-mentioned 5-chloro-3-hydroxy-2,4-dimethoxy-6-(methoxymethyl)benzoic acid, by employing the same procedure as for the preparation of **11**: clear oil; bp 160–65 °C (0.3 mmHg); IR (film) $\nu$ 1760, 1720, 1610, 1460, 1420, 1270, 1240–1200, 1135, 1100, 975, 920, 810 cm$^{-1}$; $^1$H NMR $\delta$ 4.64 (s, 2 H), 4.40 (q, 2 H, $J$ = 7.1 Hz), 3.95 (s, 3 H), 3.90 (s, 3 H), 3.36 (s, 3 H), 1.39 (t, 3 H, $J$ = 7.1 Hz) ppm; $^{13}$C NMR $\delta$ 164.80, 150.15, 148.92, 136.32, 134.90, 124.11, 118.30 (q, $J$ = 320 Hz), 109.07, 68.60, 62.54, 61.62, 61.41, 58.39, 13.67 ppm; EIMS $m/e$ (%) 436 (M$^+$, 1), 391 (5), 305 (8), 303 (22), 245 (34), 243 (100). Anal. Calcd for $C_{14}H_{16}ClF_3O_8S$: C, 38.53; H, 3.67. Found: C, 38.71; H, 3.65.

**2-(Carboxymethyl)-6-methoxyphenyl trifluoromethanesulfonate (21)** was obtained in 87% yield as a clear oil: bp 125–30 °C (0.2 mmHg); IR (film) $\nu$ 1725, 1575, 1470, 1455, 1415, 1310, 1280, 1240, 1200, 1130, 1055, 880, 790, 755 cm$^{-1}$; $^1$H NMR $\delta$ 7.56 (dd, 1 H, $J$ = 8.0 and 1.7 Hz), 7.36 (dd, 1 H, $J$ = 8.2 and 8.0 Hz), 7.19 (dd, 1 H, $J$ = 8.2 and 1.7 Hz), 3.93 (s, 3 H), 3.91 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 164.38, 151.81, 137.57, 128.41, 125.76, 123.12, 118.73 (q, $J$ = 320 Hz), 116.89, 56.37, 52.51 ppm; EIMS $m/e$ (%) 314 (M$^+$, 28), 283 (18), 181 (100), 150 (21), 149 (69), 122 (21), 121 (10), 107 (31), 79 (13), 69 (19), 65 (17). Anal. Calcd for $C_{10}H_9F_3O_6S$: C, 38.22; H, 2.87. Found: C, 38.21; H, 2.85.

**2-Formyl-6-methoxyphenyl trifluoromethanesulfonate (23)** was obtained in 80% yield as a white solid: mp 36–8 °C; IR (film) $\nu$ 1700, 1600, 1480, 1420, 1310, 1290, 1250, 1220, 1140, 1080, 910, 890, 790, 760 cm$^{-1}$; $^1$H NMR $\delta$ 10.23 (s, 1 H), 7.51 (dd, 1 H, $J$ = 7.8 and 2.2 Hz), 7.44 (t, 1 H, $J$ = 7.8 Hz), 7.29 (dd, 1 H, $J$ = 7.8 and 2.2 Hz), 3.95 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 186.58, 151.72, 139.19, 129.64, 129.07, 121.20, 118.70 (q, $J$ = 320 Hz), 118.67, 56.50 ppm; EIMS $m/e$ (%) 284 (M$^+$, 29), 151 (100), 136 (19), 108 (31), 93 (22), 80 (12), 77 (12), 69 (17), 65 (16). Anal. Calcd for $C_9H_7F_3O_5S$: C, 38.02; H, 2.46. Found: C, 38.16; H, 2.46.

**2-Methoxy-6-nitrophenyl trifluoromethanesulfonate (25)** was obtained in 70% yield as a white solid: mp 54–6 °C; IR (film) $\nu$ 3500–3200, 1600, 1540, 1520, 1460, 1420, 1340, 1290, 1240–1180, 1120, 1060, 920, 870 cm$^{-1}$; $^1$H NMR $\delta$ 7.60 (d, 1 H, $J$ = 1.7 Hz), 7.36 (d, 1 H, $J$ = 1.7 Hz), 4.80 (s, 2 H), 3.99 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 152.58, 143.10, 142.33, 129.93, 118.47 (q, $J$ = 321 Hz), 63.15, 56.93 ppm; EIMS $m/e$ (%) 331 (M$^+$, 41), 199 (10), 198 (100), 125 (12), 124 (93), 122 (31), 109 (51), 96 (15), 95 (14), 94 (13), 93 (17), 82 (17), 81 (26), 80 (12), 79 (10), 78 (12), 77 (11), 69 (44), 67 (10), 66 (21), 65 (15). Anal. Calcd for $C_9H_8NF_3O_7S$: C, 32.63; H, 2.42. Found: C, 33.07; H, 2.39.

**2-Bromo-4-(hydroxymethyl)-6-methoxyphenyl trifluoromethanesulfonate (27)** was obtained in 81% yield as a white solid: mp 64–66 °C; IR (film) $\nu$ 3570, 3500–3100, 1600, 1580, 1460, 1450, 1420, 1220–1190, 1120, 1040, 870 cm$^{-1}$; $^1$H NMR $\delta$ 7.18 (s, 1 H), 6.98 (s, 1 H), 4.67 (s, 2 H), 3.90 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 152.53, 142.88, 135.92, 122.83, 118.62 (q, $J$ = 321 Hz), 116.65, 110.15, 63.70, 56.38 ppm; EIMS $m/e$ (%) 366 (M$^+$ + 2, 17), 364 (M$^+$, 17), 233 (64), 231 (67), 177 (15), 175 (28), 173 (15), 124 (25), 109 (15), 96 (100), 95 (14), 81 (17), 69 (21). Anal. Calcd for $C_9H_8BrF_3O_5S$: C, 30.59; H, 2.19. Found: C, 30.22; H, 2.05.

**4-Formyl-2,6-dimethoxyphenyl trifluoromethanesulfonate (29)** was obtained in 73% yield as a white solid: mp 102–4 °C; IR (film) $\nu$ 1700, 1605, 1465, 1420, 1410, 1390, 1340, 1240, 1200, 1140–1110, 880, 840, 730 cm$^{-1}$; $^1$H NMR $\delta$ 9.93 (s, 1 H), 7.16 (s, 2 H), 3.98 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 190.16, 152.85, 135.76, 131.60, 118.41 (q, $J$ = 321 Hz), 105.60, 56.26 ppm; EIMS $m/e$ (%) 314 (M$^+$, 26), 181 (100), 125 (20), 110 (19), 95 (16), 93 (17), 69 (16), 65 (10). Anal. Calcd for $C_{10}H_9F_3O_6S$: C, 38.22; H, 2.87. Found: C, 38.11; H, 2.86.

**2,6-Dimethylphenyl trifluoromethanesulfonate (31)** was obtained in 93% yield as a clear oil: bp 75–80 °C (0.5 mmHg); IR (film) $\nu$ 1470, 1400, 1240–1200, 1140, 1120, 1080, 890, 880, 780, 730 cm$^{-1}$; $^1$H NMR $\delta$ 7.12 (s, 3 H), 2.38 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 145.31, 129.81, 128.17, 126.24, 117.12 (q, $J$ = 320 Hz), 15.12 ppm; EIMS $m/e$ (%) 254 (M$^+$, 20), 121 (100), 91 (46), 77 (43), 69 (18); HRMS calcd for $C_9H_9F_3O_3S$ 254.0224, found 254.0212.

**Palladium-Catalyzed Cross-Couplings of Aryl Triflates with Organostannanes. General Procedure.** To a round-bottom flask charged with a mixture of 0.5 mmol of triflate, anhydrous LiCl (0.171 g, 4.2 mmol), triphenylphosphine (0.079 g, 0.30 mmol), and $PdCl_2(PPh_3)_2$ (0.037 g, 0.06 mmol) suspended in DMF (4.5 mL) was added the organostannane (1–2 mmol; best results were obtained by addition of stannane in two portions, i.e., at the beginning of the reaction and several hours later). A crystal of inhibitor (2,6-di-*tert*-butyl-4-methylphenol) was added, and the mixture was then heated, under an inert atmosphere of argon, at 120 °C during 2–8 h (unoptimized). Water and ether (25 mL) were added, and the organic phase was washed subsequently with 1.5 N HCl (6 × 20 mL) and potassium fluoride (saturated solution) (5 × 20 mL) and finally dried over anhydrous sodium sulfate. Evaporation to dryness furnished a residue which was suspended in ethyl acetate and filtered off. The filtrate was

evaporated, and the resulting crude material was purified by column chromatography (*n*-hexane–ethyl acetate). Final crystallization or bulb-to-bulb distillation usually furnished pure products (Table I).

**2,6-Dimethoxytoluene (2a)** was obtained as a white solid in 92% yield by heating, for 6 h, **1** with 2 mmol of tetramethylstannane: mp 38–40 °C (lit[28] mp 39–41 °C); IR (film) $\nu$ 1590, 1470, 1435, 1425, 1270, 1245, 1180, 1165, 1120, 760, 705 cm$^{-1}$; $^1$H NMR $\delta$ 7.11 (t, 1 H, $J$ = 8.3 Hz), 6.52 (d, 2 H, $J$ = 8.3 Hz), 3.81 (s, 6 H), 2.09 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 158.18, 125.96, 114.17, 103.25, 55.15, 7.79 ppm; EIMS $m/e$ (%) 152 (M$^+$, 100), 137 (35), 123 (16), 122 (16), 121 (55), 109 (19), 107 (45), 105 (12), 94 (23), 91 (58), 79 (44), 78 (26), 77 (78).

**2,6-Dimethoxybiphenyl (2b)** was obtained as a white solid in 74% yield by heating **1**, for 6 h, with 1.5 mmol of tributyl(phenyl)stannane: mp 83–85 °C (*n*-hexane–ethyl acetate, 1:9); IR (film) $\nu$ 1585, 1470, 1460, 1430, 1250, 1105, 785 cm$^{-1}$; $^1$H NMR $\delta$ 7.35 (s, 5 H), 7.23 (m, 1 H), 6.65 (d, 2 H, $J$ = 8.2 Hz), 3.71 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 157.57, 134.04, 130.73, 128.43, 127.43, 126.51, 119.59, 104.20, 55.71 ppm; EIMS $m/e$ (%) 214 (M$^+$, 100), 199 (29), 184 (46), 139 (21), 128 (39), 102 (25). Anal. Calcd for $C_{14}H_{14}O_2$: C, 78.50; H, 6.54. Found: C, 78.51; H, 6.60.

**2-Allyl-1,3-dimethoxybenzene (2c)** was obtained as an oil in 84% yield by heating **1**, for 5.5 h, with 1 mmol of tributyl(allyl)stannane: bp 115–120 °C (0.1 mmHg); IR (film) $\nu$ 1625, 1595, 1470, 1255, 1210, 1125, 1110, 770 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 7.15 (t, 1 H, $J$ = 8.2 Hz), 6.55 (d, 2 H, $J$ = 8.2 Hz), 5.95 (ddt, 1 H, $J$ = 17.1, 10.1, and 6.1 Hz), 4.97 (ddt, 1 H, $J$ = 17.1, 1.9, and 1.6 Hz), 4.91 (ddt, 1 H, $J$ = 10.1, 1.9, and 1.6 Hz), 3.81 (s, 6 H), 3.41 (dt, 2 H, $J$ = 6.1 and 1.6 Hz) ppm; $^{13}$C NMR $\delta$ 158.03, 136.67, 126.88, 116.31, 113.67, 103.61, 55.42, 26.95 ppm; EIMS $m/e$ (%) 178 (M$^+$, 100), 163 (27), 149 (69), 147 (43), 135 (34), 121 (41), 115 (23), 107 (25), 105 (27), 103 (45), 91 (81), 79 (18), 78 (17), 77 (36). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.16; H, 7.87. Found: C, 74.38; H, 8.02.

**2,6-Dimethoxystyrene (2d)** was isolated as an oil in 85% yield after heating **1**, for 7 h, with 1 mmol of tributyl(vinyl)stannane: bp 95–100 °C (0.1 mmHg); IR (film) $\nu$ 1620, 1590–1570, 1470, 1430, 1410, 1255, 1120, 740 cm$^{-1}$; $^1$H NMR $\delta$ 7.15 (t, 1 H, $J$ = 8.4 Hz), 6.97 (dd, 1 H, $J$ = 18.0 and 11.9 Hz), 6.53 (d, 2 H, $J$ = 8.4 Hz), 6.46 (dd, 1 H, $J$ = 18.0 and 3.0 Hz), 5.86 (dd, 1 H, $J$ = 11.9 and 3.0 Hz), 3.83 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 158.43, 128.01, 127.15, 118.10, 114.82, 103.79, 55.45 ppm; EIMS $m/e$ (%) 164 (M$^+$, 48), 149 (75), 121 (28), 91 (100), 78 (26), 77 (23); HRMS calcd for $C_{10}H_{12}O_2$ 164.08372, found 164.08360.

**1,3-Dimethoxy-2-(phenylethynyl)benzene (2e)** was prepared in 50% yield by heating **1**, for 5 h, with 1.5 mmol of tributyl(phenylethynyl)stannane and the catalytic system $PdCl_2(PPh_3)_2$ (15 mol %)/dppf (0.25 mmol): brownish solid; mp 80–82 °C (*n*-hexane–ethyl acetate, 1:9); IR (film) $\nu$ 2200, 1590, 1580, 1475, 1435, 1260, 1120, 785, 765, 700 cm$^{-1}$; $^1$H NMR $\delta$ 7.58 (m, 2 H), 7.30 (m, 4 H), 6.54 (d, 2 H, $J$ = 8.5 Hz), 3.89 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 161.22, 131.44, 129.52, 127.91, 127.62, 123.85, 103.44, 101.55, 97.64, 81.82, 55.89 ppm; EIMS $m/e$ (%) 238 (M$^+$, 100), 237 (40), 223 (16), 222 (21), 165 (28), 161 (25), 152 (37), 126 (36). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.67; H, 5.88. Found: C, 80.38; H, 5.92.

**2,2′,6-Trimethoxybiphenyl (2g)** was obtained in 33% yield as a white solid from the cross-coupling of **1** (0.25 mmol) and tributyl(*o*-methoxyphenyl)stannane[29] (0.5 mmol), by heating at 140 °C for 24 h with 20 mmol % of $PdCl_2(PPh_3)_2$: white solid; mp 132–34 °C; IR (film) $\nu$ 2900, 1575, 1460, 1420, 1240, 1100 cm$^{-1}$; $^1$H NMR $\delta$ 7.36 (dd, 1 H, $J$ = 7.3 and 1.3 Hz), 7.28 (t, 1 H, $J$ = 8.3 Hz), 7.17 (dd, 1 H, $J$ = 7.3 and 1.3 Hz), 7.02 (dd, 1 H, $J$ = 7.3 and 1.3 Hz), 6.98 (d, 1 H, $J$ = 8.3 Hz), 6.64 (d, 2 H, $J$ = 8.3 Hz), 3.74 (s, 3 H), 3.71 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 158.08, 157.46, 132.19, 132.23, 131.53, 128.70, 128.51, 120.26, 111.24, 104.23, 56.02, 55.83 ppm; EIMS $m/e$ (%) 245 (M$^+$ + 1, 15), 244 (M$^+$, 100), 213 (11), 198 (14), 183 (9), 155 (9), 121 (13); HRMS calcd for $C_{15}H_{16}O_3$ 244.10994, found 244.1106.

**2-Methoxy-6-(methoxymethyl)toluene (4a)** was prepared in 96% yield by heating **3**, for 8 h, with 2 mmol of tetramethylstannane: oil; bp 70–75 °C (0.1 mmHg); IR (film) $\nu$ 1585, 1470, 1375, 1210, 1115, 1090, 780 cm$^{-1}$; $^1$H NMR $\delta$ 7.15–6.74 (m, 3 H), 4.44 (s, 2 H), 3.81 (s, 3 H), 3.38 (s, 3 H), 2.19 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 157.56, 137.16, 125.78, 125.16, 120.88, 109.67, 72.89, 57.84, 55.36, 10.60 ppm; EIMS $m/e$ (%) 166 (M$^+$, 23), 135 (25), 134 (100), 105 (30), 104 (53), 91 (36), 77 (19). Anal. Calcd for $C_{10}H_{14}O_2$: C, 72.29; H, 8.43. Found: C, 72.15; H, 8.49.

**2-Methoxy-6-(methoxymethyl)biphenyl (4b)** was isolated as an oil in 79% yield by reacting (7 h) **3** with 1.5 mmol of tributyl(phenyl)stannane: bp 155–160 °C (0.1 mmHg); IR (film) $\nu$ 1600, 1580, 1470, 1255, 1075, 1070 cm$^{-1}$; $^1$H NMR $\delta$ 7.43–7.18 (m, 7 H), 6.90 (dd, 1 H, $J$ = 7.8 and 1.2 Hz), 4.13 (s, 2 H), 3.70 (s, 3 H), 3.24 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 156.57, 137.58, 136.16, 130.31, 129.87, 128.12, 127.62, 126.75, 120.38, 110.04, 72.95, 57.89, 55.56 ppm; EIMS $m/e$ (%): 229 (M$^+$ + 1, 16), 228 (M$^+$, 100), 198 (15), 197 (37), 196 (26), 195 (36), 182 (18), 181 (41), 165 (43), 153 (19), 152 (30), 151 (14). Anal. Calcd for $C_{15}H_{16}O_2$: C, 78.95; H, 7.02. Found: C, 78.95; H, 7.06.

**2-Allyl-1-methoxy-3-(methoxymethyl)benzene (4c)** was prepared in 99% yield by heating **3**, for 5 h with 1 mmol of tributyl(allyl)stannane: oil; bp 100–105 °C (0.1 mmHg); IR (film) $\nu$ 1640, 1590, 1470, 1440, 1255, 1100, 1075, 915, 780, 760 cm$^{-1}$; $^1$H NMR $\delta$ 7.29–6.77 (m, 3 H), 5.90 (ddt, 1 H, $J$ = 18.0, 9.0, and 5.9 Hz), 4.93 (dd, 1 H, $J$ = 9.0 and 1.7 Hz), 4.89 (dd, 1 H, $J$ = 18.0 and 1.7 Hz), 4.44 (s, 2 H), 3.80 (s, 3 H), 3.46 (d, 2 H, $J$ = 5.9 Hz), 3.37 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 157.50, 137.42, 136.50, 126.73, 126.65, 121.07, 114.16, 110.13, 72.29, 57.89, 55.50, 29.49 ppm; EIMS $m/e$ (%) 192 (M$^+$, 9), 161 (23), 160 (100), 159 (74), 145 (62), 144 (31), 129 (46), 128 (25), 127 (18), 117 (22), 115 (44), 91 (33), 77 (20). Anal. Calcd for $C_{12}H_{16}O_2$: C, 75.00; H, 8.33. Found: C, 74.89; H, 8.42.

**2-Methoxy-6-(methoxymethyl)styrene (4d)** was synthesized in 90% yield by heating **3**, for 3 h, with 1 mmol of tributyl(vinyl)stannane: oil; bp 100–105 °C (0.08 mmHg); IR (film) $\nu$ 1595, 1570, 1465, 1455, 1435, 1375, 1255, 1190, 1100–1070, 920, 880, 850 cm$^{-1}$; $^1$H NMR $\delta$ 7.32–6.63 (m, 4 H), 5.65 (dd, 1 H, $J$ = 11.7 and 2.4 Hz), 5.47 (dd, 1 H, $J$ = 5.1 and 2.4 Hz), 4.48 (s, 2 H), 3.82 (s, 3 H), 3.38 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 157.32, 136.76, 130.16, 127.48, 126.45, 121.42, 119.57, 109.99, 72.55, 57.65, 55.31 ppm; EIMS $m/e$ (%) 178 (M$^+$, 23), 163 (37), 147 (25), 146 (21), 145 (16), 135 (15), 131 (32), 121 (20), 120 (20), 117 (17), 115 (37), 105 (33), 103 (34), 91 (41), 79 (17), 77 (32). Anal. Calcd for $C_{11}H_{14}O_2$: C, 74.16; H, 7.87. Found: C, 73.98; H, 8.04.

**1-Methoxy-3-(methoxymethyl)-2-(phenylethynyl)benzene (4e)** was obtained in 56% yield by heating **3**, for 5.5 h, with 1.5 mmol of tributyl(phenylethynyl)stannane: oil; bp 175–180 °C (0.15 mmHg); IR (film) $\nu$ 1590, 1570, 1490, 1470, 1455, 1435, 1265, 1070, 750, 690 cm$^{-1}$; $^1$H NMR $\delta$ 7.63–7.05 (m, 8 H), 6.82 (dd, 1 H, $J$ = 7.9 and 1.2 Hz), 4.70 (s, 2 H), 3.89 (s, 3 H), 3.46 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 160.00, 141.87, 131.38, 129.10, 128.11, 128.04, 123.50, 119.41, 110.87, 109.50, 98.27, 83.06, 72.49, 58.38, 55.81 ppm; EIMS $m/e$ (%) 253 (M$^+$ + 1, 14), 252 (M$^+$, 67), 238 (15), 237 (100), 222 (76), 221 (36), 194 (24), 190 (21), 178 (27), 165 (31), 76 (15). Anal. Calcd for $C_{17}H_{16}O_2$: C, 80.95; H, 6.35. Found: C, 80.94; H, 6.40.

**2,2′-Dimethoxy-6-(methoxymethyl)biphenyl (4g)** was obtained in 46% yield as a white solid from the cross-coupling of **3** (0.25 mmol) and tributyl(*o*-methoxyphenyl)stannane[29] (0.75 mmol) by heating at 145 °C for 23 h: oil; bp 115–20 °C (0.12 mmHg); IR (film) $\nu$ 2900, 1580, 1500, 1460, 1430, 1250, 1120, 1080, 760 cm$^{-1}$; $^1$H NMR $\delta$ 7.35 (m, 2 H), 7.14 (m, 2 H), 7.01 (d, 1 H, $J$ = 7.3 Hz), 6.97 (d, 1 H, $J$ = 8.2 Hz), 6.91 (d, 1 H, $J$ = 8.2 Hz), 4.19 (d, 1 H, $J$ = 12.5 Hz), 4.09 (d, 1 H, $J$ = 12.5 Hz), 3.72 (s, 3 H), 3.71 (s, 3 H), 3.22 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 157.03, 138.44, 137.60, 136.89, 128.77, 128.39, 126.45, 125.14, 120.36, 119.36, 110.90, 110.02, 72.05, 58.10, 55.93, 55.57 ppm; EIMS $m/e$ (%) 259 (M$^+$ + 1, 16), 258 (M$^+$, 100), 228 (19), 227 (34), 226 (23), 225 (21), 215 (18), 212 (15), 211 (47), 200 (15), 197 (16), 196 (29), 195 (62), 181 (22), 168 (29), 165 (15), 152 (26), 151 (22), 139 (17), 115 (15); HRMS calcd for $C_{16}H_{18}O_3$ 258.12559, found 258.1262.

**2-Allyl-4-chloro-1,3-dimethoxy-5-(methoxymethyl)benzene (6c)** was obtained in 63% yield by heating **5**, for 7 h, with 1.5 mmol of tributyl(allyl)stannane: oil; bp 135–140 °C (0.15 mmHg); IR (film) $\nu$ 1595, 1570, 1410, 1400, 1370, 1320, 1205, 1195, 1160, 1125, 1105, 1045, 990, 910, 850 cm$^{-1}$; $^1$H NMR $\delta$ 6.81 (s, 1 H), 5.91 (ddt, 1 H, $J$ = 17.5, 9.4, and 6.0 Hz), 4.97 (dd, 1 H, $J$ = 17.5 and 1.6 Hz), 4.94 (dd, 1 H, $J$ = 9.4 and 1.6 Hz), 4.53 (s, 2 H), 3.82 (s, 6 H), 3.47 (s, 3 H), 3.43 (d, 2 H, $J$ = 6.0 Hz) ppm; $^{13}$C NMR $\delta$ 156.81, 154.53, 136.41, 135.29, 122.40, 118.10, 114.58, 106.25, 71.62, 60.96, 58.47, 55.70, 28.36 ppm; EIMS $m/e$ (%) 258 (M$^+$ + 2, 33), 256 (M$^+$, 100), 225 (23), 221 (30), 195 (19). Anal. Calcd for $C_{13}H_{17}O_3Cl$:

C, 60.82; H, 6.63. Found: C, 60.98; H, 6.82.

**3-Allyl-2,6-dimethoxy-4-(methoxymethyl)phenyl trifluormethanesulfonate (8c)** was prepared in 92% yield by heating **7** for 6.5 h with 0.75 mmol of tributyl(allyl)stannane (neither LiCl nor triphenylphosphine added): oil; bp 160–165 °C (0.12 mmHg); IR (film) $\nu$ 1610, 1490, 1460, 1420, 1335, 1230–1190, 1135, 1120, 1010, 920, 825 cm$^{-1}$; $^1$H NMR $\delta$ 6.92 (s, 1 H), 5.90 (ddt, 1 H, $J$ = 17.8, 9.2, and 5.3 Hz), 5.05 (dd, 1 H, $J$ = 9.2 and 1.7 Hz), 4.86 (dd, 1 H, $J$ = 17.8 and 1.7 Hz), 4.41 (s, 2 H), 3.90 (s, 3 H), 3.81 (s, 3 H), 3.43 (s, 3 H), 3.40 (d, 2 H, $J$ = 5.3 Hz) ppm; $^{13}$C NMR $\delta$ 151.11, 150.24, 138.08, 135.92, 131.41, 123.61, 118.45 (q, $J$ = 320 Hz), 114.89, 107.51, 71.23, 61.47, 58.09, 55.80, 30.17, 29.00 ppm; EIMS $m/e$ (%) 370 (M$^+$, 5), 205 (100), 177 (17), 168 (25). Anal. Calcd for $C_{14}H_{17}F_3O_2S$: C, 45.40; H, 4.59. Found: C, 45.64; H, 4.70.

**2,4-Diallyl-1,3-dimethoxy-5-(methoxymethyl)benzene (8cc)** was prepared in 67% yield by heating **7**, for 7 h, with 2 mmol of allyltributylstannane: oil; bp 150–155 °C (0.12 mmHg); IR (film) $\nu$ 1635, 1605, 1580, 1460, 1450, 1410, 1220, 1190, 1125, 1100, 1055, 910 cm$^{-1}$; $^1$H NMR $\delta$ 6.76 (s, 1 H), 5.96 (m, 2 H), 4.90 (m, 4 H), 4.41 (s, 2 H), 3.81 (s, 3 H), 3.70 (s, 3 H), 3.40 (m, 7 H) ppm; $^{13}$C NMR $\delta$ 159.91, 157.49, 137.38, 137.08, 136.30, 122.86, 120.87, 114.44, 114.15, 106.76, 72.19, 61.88, 58.14, 55.49, 29.66, 28.35 ppm; EIMS $m/e$ (%) 262 (M$^+$, 24), 231 (21), 230 (100), 229 (20), 215 (21), 201 (21), 199 (35), 189 (28), 188 (21), 91 (17). Anal. Calcd for $C_{16}H_{22}O_3$: C, 73.28; H, 8.40. Found: C, 73.38; H, 8.34.

**2,6-Dimethoxy-4-(methoxymethyl)-3-(methylthio)toluene (10a)** was synthesized in 58% yield from the corresponding triflate **9**: oil; bp 160–165 °C (0.02 mmHg); IR (film) $\nu$ 1585, 1560, 1455, 1445, 1435, 1380, 1300, 1120 cm$^{-1}$; $^1$H NMR $\delta$ 6.80 (s, 1 H), 4.68 (s, 2 H), 3.84 (s, 6 H), 3.45 (s, 3 H), 2.31 (s, 3 H), 2.15 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 160.47, 158.75, 140.32, 119.60, 105.89, 102.86, 72.92, 60.37, 58.18, 55.45, 19.16, 9.10 ppm; EIMS $m/e$ (%) 242 (M$^+$ + 2, 6), 241 (M$^+$ + 1, 14), 376 (M$^+$, 84), 227 (100), 212 (17), 196 (19), 195 (30), 165 (17), 152 (26), 151 (22), 137 (15), 91 (25), 77 (22). Anal. Calcd for $C_{12}H_{18}O_3S$: C, 59.50; H, 7.44. Found: C, 60.04; H, 7.40.

**Ethyl 3-allyl-2,4-dimethoxy-6-(methoxymethyl)benzoate (12c)** was isolated in 68% yield by heating **11**, for 3 h, with 1.5 mmol of tributyl(allyl)stannane: oil; bp 155–160 °C (0.2 mmHg); IR (film) $\nu$ 1720, 1600, 1570, 1460, 1410, 1295, 1260, 1150, 1110 cm$^{-1}$; $^1$H NMR $\delta$ 6.74 (s, 1 H), 5.93 (ddt, 1 H, $J$ = 17.4, 9.9, and 5.5 Hz), 4.96 (dd, 1 H, $J$ = 17.4 and 1.7 Hz), 4.95 (dd, 1 H, $J$ = 9.9 and 1.7 Hz), 4.48 (s, 2 H), 4.37 (q, 2 H, $J$ = 7.1 Hz), 3.83 (s, 3 H), 3.77 (s, 3 H), 3.40 (d, 2 H, $J$ = 5.5 Hz), 3.36 (s, 3 H), 1.37 (t, 3 H, $J$ = 7.1 Hz) ppm; $^{13}$C NMR $\delta$ 167.41, 159.32, 156.69, 136.42, 136.23, 121.04, 119.67, 114.41, 105.64, 72.08, 62.58, 60.71, 58.01, 55.49, 27.71, 13.92 ppm; EIMS $m/e$ (%) 294 (M$^+$, 8), 249 (21), 248 (32), 234 (15), 233 (100), 161 (6), 147 (6), 115 (10), 91 (13), 77 (11). Anal. Calcd for $C_{16}H_{22}O_5$: C, 65.31; H, 7.48. Found: C, 65.38; H, 7.55.

**6-Allyl-1,3-dihydro-5,7-dimethoxyisobenzofuran-1-one (14c)** was isolated in 34% yield by heating **13**, for 2 h, with 1.5 mmol of tributyl(allyl)stannane as a white solid: mp 92–94 °C; IR (film) $\nu$ 2910, 1740, 1590, 1460, 1420, 1330, 1220, 1200, 1130, 1060, 1000, 990, 940, 900, 840, 790 cm$^{-1}$; $^1$H NMR $\delta$ 6.74 (s, 1 H), 5.93 (ddt, 1 H, $J$ = 17.4, 9.9, and 5.5 Hz), 4.96 (dd, 1 H, $J$ = 17.4 and 1.7 Hz), 4.95 (dd, 1 H, $J$ = 9.9 and 1.7 Hz), 4.48 (s, 2 H), 4.37 (q, 2 H, $J$ = 7.1 Hz), 3.83 (s, 3 H), 3.77 (s, 3 H), 3.40 (d, 2 H, $J$ = 5.5 Hz), 3.36 (s, 3 H), 1.37 (t, 3 H, $J$ = 7.1 Hz) ppm; $^{13}$C NMR $\delta$ 167.41, 159.32, 156.69, 136.42, 136.23, 121.04, 119.67, 114.41, 105.64, 72.08, 62.58, 60.71, 58.01, 55.49, 27.71, 13.92 ppm; EIMS $m/e$ (%) 294 (M$^+$, 8), 249 (21), 248 (32), 234 (15), 233 (100), 161 (6), 147 (6), 115 (10), 91 (13), 77 (11). Anal. Calcd for $C_{16}H_{22}O_5$: C, 66.67; H, 5.98. Found: C, 66.50; H, 6.13.

**1-Allyl-3,5-dichloro-2,6-dimethoxy-4-(methoxymethyl)-benzene (18c)** was isolated in 28% yield by heating **17**, for 6 h, with 1.5 mmol of allyltributylstannane as an oil: bp 120–5 °C (0.1 mmHg); IR (film) $\nu$ 2950, 1465, 1410, 1120 cm$^{-1}$; $^1$H NMR $\delta$ 5.93 (ddt, 1 H, $J$ = 17.0, 10.1, and 6.0 Hz), 5.05 (dd, 1 H, $J$ = 10.1 and 1.6 Hz), 5.01 (dd, 1 H, $J$ = 17.0 and 1.6 Hz), 4.74 (s, 2 H), 3.83 (s, 6 H), 3.46 (s and partially resolved d, 2 H) ppm; $^{13}$C NMR $\delta$ 153.92, 136.15, 133.03, 130.19, 126.21, 115.83, 59.16, 58.67, 29.66 ppm; EIMS $m/e$ (%) 293 (M$^+$ + 3, 11), 291 (M$^+$ + 2, 63), 291 (M$^+$ + 1, 17), 290 (M$^+$, 100), 261 (25), 259 (34), 257 (11), 255 (36), 229 (11), 227 (16), 225 (44), 209 (14), 195 (11), 75 (13); HRMS calcd for $C_{13}H_{16}Cl_2O_3$ 290.04764, found 290.0474.

**2-(Carboxymethyl)-6-methoxybiphenyl (22b)** was obtained in 87% yield by heating **21** (0.25 mmol), for 7 h, with 0.5 mmol of tributyl(phenyl)stannane as an oil: bp 145–50 °C (0.45 mmHg); IR (film) $\nu$ 2950, 1730, 1590, 1470, 1460, 1440, 1300, 1260, 1200, 1150, 1065, 765, 740, 705 cm$^{-1}$; $^1$H NMR $\delta$ 7.38 (m, 5 H), 7.26 (m, 2 H), 7.10 (dd, 1 H, $J$ = 6.4 and 3.0 Hz), 3.76 (s, 3 H), 3.54 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 168.89, 156.93, 136.75, 133.30, 131.04, 129.48, 128.42, 127.68, 127.09, 121.35, 113.87, 56.02, 51.90 ppm; EIMS $m/e$ (%) 243 (M$^+$ + 1, 17), 242 (M$^+$, 100), 212 (18), 211 (94), 209 (17), 196 (62), 181 (22), 168 (35), 152 (21), 139 (47); HRMS calcd for $C_{15}H_{14}O_3$ 242.09429, found 242.0948.

**Methyl 2-allyl-3-methoxybenzoate (22c)** was obtained in 97% yield by heating **21** (0.25 mmol), for 0.5 h, with 0.5 mmol of tributyl(allyl)stannane as an oil: bp 87–92 °C (0.12 mmHg); IR (film) $\nu$ 2950, 1720, 1705, 1630, 1580, 1460, 1430, 1320, 1280, 1270, 1240, 1220, 1190, 1140, 1090, 1060, 1050, 1000, 900, 880, 860 cm$^{-1}$; $^1$H NMR $\delta$ 7.38 (d, 1 H, $J$ = 7.5 Hz), 7.22 (dd, 1 H, $J$ = 8.1 and 7.5 Hz), 6.99 (d, 1 H, $J$ = 8.1 Hz), 6.00 (ddt, 1 H, $J$ = 17.0, 11.0, and 6.1 Hz), 4.95 (dd, 1 H, $J$ = 17.0 and 1.8 Hz), 4.93 (dd, 1 H, $J$ = 11.0 and 1.8 Hz), 3.85 (s, 3 H), 3.83 (s, 3 H), 3.72 (d, 2 H, $J$ = 6.1 Hz) ppm; $^{13}$C NMR $\delta$ 168.34, 157.96, 136.97, 129.88, 126.80, 122.20, 114.57, 113.94, 55.95, 51.88, 30.46 ppm; EIMS $m/e$ (%) 206 (M$^+$, 65), 192 (12), 191 (100), 176 (16), 175 (56), 174 (23), 163 (26), 160 (16), 159 (50), 147 (18), 145 (13), 132 (14), 131 (45), 117 (11), 116 (11), 115 (41), 105 (16), 103 (36), 91 (37), 89 (10), 78 (11), 77 (33). Anal. Calcd for $C_{12}H_{14}O_3$: C, 69.90; H, 6.80. Found: C, 69.87; H, 6.94.

**8-Methoxy-2-methylchromene (24c)** was obtained in 34% yield by heating **23** (0.25 mmol), for 6 h, with 0.3 mmol of tributyl(allyl)stannane as an oil: bp 125–30 °C (0.2 mmHg); IR (film) $\nu$ 1570, 1480, 1440, 1390, 1260, 1220, 1180, 790 cm$^{-1}$; $^1$H NMR $\delta$ 6.78 (m, 2 H), 6.62 (dd, 1 H, $J$ = 6.6 and 2.4 Hz), 6.37 (dd, 1 H, $J$ = 9.8 and 1.7 Hz), 5.68 (dd, 1 H, $J$ = 9.8 and 3.2 Hz), 5.08 (qd, 1 H, $J$ = 6.5 and 3.2 Hz), 3.87 (s, 3 H), 1.49 (d, 3 H, $J$ = 6.5 Hz) ppm; $^{13}$C NMR $\delta$ 147.95, 142.21, 126.96, 123.66, 122.48, 120.57, 118.88, 112.13, 71.65, 56.05, 21.29 ppm; EIMS $m/e$ (%) 176 (M$^+$, 25), 175 (8), 162 (10), 161 (100), 146 (22), 118 (7), 77 (7); HRMS calcd for $C_{11}H_{11}O_2$ 175.07590, found 175.0752.

**1-Allyl-2-(1-hydroxy-3-buten-1-yl)-3-methoxybenzene (24cc)** was obtained in 55% yield by heating **23**, for 5 h, with 1 mmol of tributyl(allyl)stannane: oil; bp 95–100 °C (0.1 mmHg); IR (film) $\nu$ 3500–3250, 2900, 1630, 1580, 1460, 1430, 1250, 1160, 1140, 990, 910, 780 cm$^{-1}$; $^1$H NMR $\delta$ 7.24 (t, 1 H, $J$ = 7.9 Hz), 7.12 (dd, 1 H, $J$ = 7.9 and 1.5 Hz), 6,80 (dd, 1 H, $J$ = 7.9 and 1.5 Hz), 5.89 (m, 2 H), 4.99 (m, 5 H), 3.80 (s, 3 H), 3.53 (ddt, 1 H, $J$ = 15.7, 6.0, and 1.8 Hz), 3.41 (ddt, 1 H, $J$ = 15.7, 6.0, and 1.8 Hz), 2.45 (m, 2 H) ppm; $^{13}$C NMR $\delta$ 157.32, 143.48, 137.13, 134.94, 127.34, 124.98, 117.96, 117.84, 114.57, 109.58, 69.48, 55.66, 42.96, 29.35 ppm; EIMS $m/e$ (%) 218 (M$^+$, 4), 178 (11), 177 (97), 160 (12), 159 (100), 145 (10), 144 (67), 129 (11), 128 (12), 127 (12), 121 (27), 115 (26), 91 (39), 77 (18). Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.06; H, 8.26. Found: C, 76.85; H, 8.22.

**2-Allyl-4-(hydroxymethyl)-6-methoxyphenyl trifluoromethanesulfonate (28c)** was obtained in 67% yield as an oil, by heating **27**, for 2 h, with 0.75 mmol of tributyl(allyl)stannane: bp 120–5 °C (0.12 mmHg); IR (film) $\nu$ 3560, 3500–3100, 1600, 1580, 1460, 1410, 1220–1190, 1120, 1040, 870 cm$^{-1}$; $^1$H NMR $\delta$ 6.92 (d, 1 H, $J$ = 1.8 Hz), 6.82 (d, 1 H, $J$ = 1.8 Hz), 5.87 (ddt, 1 H, $J$ = 16.5, 10.5, and 6.7 Hz), 5.13 (ddt, 1 H, $J$ = 10.5, 1.4, and 1.3 Hz), 5.11 (ddt, 1 H, $J$ = 16.5, 1.4, and 1.3 Hz), 4.66 (s, 2 H), 3.88 (s, 3 H), 3.72 (d, 2 H, $J$ = 6.7 Hz) ppm; $^{13}$C NMR $\delta$ 151.34, 141.78, 134.52, 134.07, 120.03, 118.7 (q, $J$ = 320 Hz), 117.31, 109.22, 104.83, 64.30, 56.01, 33.92 ppm; EIMS $m/e$ (%) 326 (M$^+$, 25), 194 (12), 193 (100), 175 (11), 163 (13), 148 (18), 137 (12), 135 (10), 133 (11), 131 (12), 115 (13), 105 (41), 103 (31), 91 (24), 79 (22), 77 (24), 69 (21), 65 (14). Anal. Calcd for $C_{12}H_{13}F_3O_5S$: C, 44.17; H, 3.99. Found: C, 44.21; H, 4.04.

**3,4-Diallyl-5-methoxybenzyl alcohol (28cc)** was obtained in 41% yield by heating **27**, for 6 h, with 2.3 mmol of tributyl-(allyl)stannane: oil; bp 125–130 °C (0.2 mmHg); IR (film) $\nu$ 3500–3200, 3060, 2995, 2930, 1640, 1605, 1580, 1460, 1420, 1290, 1200, 1140, 1060, 1000, 910 cm$^{-1}$; $^1$H NMR $\delta$ 6.78 (s, 1 H), 6.76 (s, 1 H), 5.92 (ddt, 1 H, $J$ = 16.7, 10.4, and 6.7 Hz), 5.89 (ddt, 1 H, $J$ = 16.7, 10.4, and 6.7 Hz), 5.03 (d, 1 H, $J$ = 10.4 Hz), 5.00 (d, 1 H, $J$ = 16.7 Hz), 4.92 (d, 1 H, $J$ = 10.4 Hz), 4.88 (d, 1 H,

$J$ = 16.7 Hz), 4.63 (s, 2 H), 3.81 (s, 3 H), 3.39 (d, 2 H, $J$ = 6.7 Hz), 3.36 (d, 2 H, $J$ = 6.7 Hz) ppm; $^{13}$C NMR $\delta$ 157.98, 139.79, 137.09, 136.64, 125.97, 120.43, 115.69, 114.37, 107.46, 104.83, 65.44, 55.68, 37.09, 29.79 ppm; EIMS $m/e$ (%) 219 ($M^+$ + 1, 14), 218 ($M^+$, 96), 203 (14), 189 (23), 187 (47), 185 (19), 173 (39), 172 (23), 171 (36), 161 (12), 160 (17), 159 (100), 158 (39), 157 (14), 147 (33), 146 (22), 145 (22), 144 (60), 142 (11), 141 (18), 132 (16), 131 (26), 129 (38), 128 (47), 127 (25), 117 (17), 116 (19), 115 (67), 103 (15), 91 (45), 77 (27); HRMS calcd for $C_{14}H_{18}O_2$ 218.1307, found 218.1309.

**4-Allyl-3,5-dimethoxybenzaldehyde (30c)** was prepared in 78% yield by heating **29** (0.25 mmol), for 0.5 h, with 0.3 mmol of tributyl(allyl)stannane as a white solid: mp 32–33 °C; IR (film) $\nu$ 2900, 2800, 1680, 1570, 1440, 1400, 1370, 1300, 1200, 1130, 1070, 900, 820 cm$^{-1}$; $^1$H NMR $\delta$ 9.91 (s, 1 H), 7.06 (s, 2 H), 5.85 (ddt, 1 H, $J$ = 17.2, 10.4, and 6.4 Hz), 4.95 (dd, 1 H, $J$ = 17.2 and 1.5 Hz), 4.89 (dd, 1 H, $J$ = 10.4 and 1.5 Hz), 3.88 (s, 6 H), 3.45 (d, 2 H, $J$ = 6.4 Hz) ppm; $^{13}$C NMR $\delta$ 191.41, 158.36, 135.61, 135.27, 123.85, 114.61, 104.80, 55.73, 27.42 ppm; EIMS $m/e$ (%) 207 ($M^+$ + 1, 15), 206 ($M^+$, 100), 177 (18), 163 (14), 149 (36), 147 (23), 135 (26), 134 (15), 123 (32), 119 (15), 115 (35), 107 (19), 105 (21), 103 (30), 91 (65), 79 (15), 77 (39), 65 (21). Anal. Calcd for $C_{12}H_{14}O_3$: C, 69.90; H, 6.80. Found: C, 69.98; H, 6.99.

**2-Allyl-1,3-dimethylbenzene (32c)** was obtained in 62% yield by heating **31** (1 mmol), for 6 h, with 2.5 mmol of tributyl(allyl)stannane: oil; bp 35–40 °C (0.1 mmHg); IR (film) $\nu$ 2900, 1615, 1460, 1440, 1370, 980, 900, 760 cm$^{-1}$; $^1$H NMR $\delta$ 7.01 (s, 3 H), 5.89 (ddt, 1 H, $J$ = 17.0, 10.2, and 5.6 Hz), 4.98 (ddt, 1 H, $J$ = 10.2, 1.9, and 1.8 Hz), 4.84 (ddt, 1 H, $J$ = 17.0, 1.9, and 1.8 Hz), 3.39 (dt, 2 H, $J$ = 5.6 and 1.8 Hz), 2.28 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 136.64, 136.11, 135.28, 128.00, 126.02, 114.81, 33.62, 19.77 ppm; EIMS $m/e$ (%) 146 ($M^+$, 42), 131 (100), 129 (15), 116 (16), 115 (19), 91 (29); HRMS calcd for $C_{11}H_{14}$ 146.1096, found 146.1111.

**2,6-Dimethyl-2′-methoxybiphenyl (32g)** was synthesized in 57% yield by heating **31** (0.25 mmol), at 140 °C for 9 h, with 0.5 mmol of tributyl(*o*-methoxyphenyl)stannane[29] and 10 mol % $PdCl_2(PPh_3)_2$ without additional $PPh_3$: oil; bp 95–100 °C (0.12 mmHg); IR (film) $\nu$ 2940, 1580, 1500, 1460, 1430, 1260, 1240, 1230, 1120, 1030, 760 cm$^{-1}$; $^1$H NMR $\delta$ 7.36 (m, 1 H), 7.15 (m, 3 H), 7.03 (m, 3 H), 3.75 (s, 3 H), 2.03 (s, 6 H) ppm; $^{13}$C NMR $\delta$ 156.52, 138.21, 136.61, 130.66, 129.52, 128.38, 127.97, 127.02, 120.67, 110.86, 55.44, 20.46 ppm; EIMS $m/e$ (%) 212 ($M^+$, 100), 197 (43), 182 (26), 181 (52), 179 (15), 166 (18), 165 (34), 152 (16); HRMS calcd for $C_{15}H_{16}O$ 212.1201, found 212.1179.

**4-Chloro-1,3-dihydro-5,6-dihydroxy-7-methoxyisobenzofuran-1-one (33)** was obtained in 34% yield by heating **15**, for 4 h, with 1.25 mmol of tributyl(allyl)stannane: white solid; mp 95–97 °C; IR (film) $\nu$ 3500–3000, 1730, 1600, 1500, 1470, 1460, 1440, 1360, 1325, 1250, 1090, 1050, 1025, 960, 925, 830 cm$^{-1}$; $^1$H NMR $\delta$ 5.16 (s, 2 H), 4.24 (s, 3 H) ppm; $^{13}$C NMR $\delta$ 169.40, 149.08, 144.64, 138.64, 137.55, 108.85, 108.53, 68.04, 62.38; EIMS $m/e$ (%) 232 ($M^+$ + 2, 28), 231 ($M^+$ + 1, 40), 230 ($M^+$, 77), 229 (93), 214 (28), 213 (33), 212 (60), 203 (12), 201 (35), 199 (16), 186 (37), 185 (37), 184 (26), 183 (100), 171 (23), 155 (16); HRMS calcd for $C_9H_7ClO_5$ 229.99820, found 229.9977.

**Ethyl 3-chloro-4,5-dihydroxy-6-methoxy-2-(methoxymethyl)benzoate (34)** was synthesized in 40 % yield by heating **19**, for 2 h, with 1.5 mmol of tetramethylstannane: oil; bp 155–160 °C (0.1 mmHg); IR (film) $\nu$ 3500–3100, 1720, 1600, 1460, 1440, 1370, 1300, 1280, 1100, 1025, 810 cm$^{-1}$; $^1$H NMR $\delta$ 4.56 (s, 2 H), 4.38 (q, 2 H, $J$ = 7.1 Hz), 3.88 (s, 3 H), 3.33 (s, 3 H), 1.39 (t, 3 H, $J$ = 7.1 Hz) ppm; $^{13}$C NMR $\delta$ 166.69, 143.90, 141.78, 137.36, 124.73, 121.90, 116.50, 68.74, 61.93, 61.55, 58.25, 14.17 ppm; EIMS $m/e$ (%) 292 ($M^+$ + 2, 5), 290 ($M^+$, 14), 247 (5), 246 (8), 245 (15), 244 (21), 232 (4), 231 (35), 230 (11), 229 (100), 216 (4), 215 (10), 214 (10), 213 (14), 187 (9), 185 (14), 182 (10); HRMS calcd for $C_{12}H_{15}ClO_6$ 290.05571, found 290.0559.

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**Registry No.** **1**, 60319-07-5; **2a**, 5673-07-4; **2b**, 13732-86-0; **2c**, 3698-35-9; **2d**, 21897-50-7; **2e**, 128920-00-3; **2f**, 16929-66-1; **2g**, 70388-58-8; **3**, 128919-93-7; **3** phenol derivative, 104199-12-4; **4a**, 128919-94-8; **4b**, 128920-01-4; **4c**, 128920-02-5; **4d**, 128920-03-6; **4e**, 137898-00-1; **4g**, 137898-01-2; **5**, 128919-95-9; **5** phenol derivative, 137898-24-9; **6c**, 128919-96-0; **7**, 128919-97-1; **7** phenol derivative, 137898-25-0; **8c**, 128919-98-2; **8cc**, 128920-04-7; **9**, 124200-74-4; **10a**, 128919-99-3; **11**, 137898-02-3; **11** phenol derivative, 137898-26-1; **12c**, 124200-75-5; **14c**, 137898-04-5; **15**, 137898-05-6; **15** phenol derivative, 137898-27-2; **16c**, 137898-06-7; **17**, 137898-07-8; **17** phenol derivative, 137898-08-9; **19**, 137898-09-0; **20c**, 137898-10-3; **21**, 132338-45-5; **21** phenol derivative, 6342-70-7; **22**, 137898-11-4; **22b**, 137898-12-5; **22g**, 35394-27-5; **23**, 137898-13-6; **23** phenol derivative, 148-53-8; **24cc**, 137898-14-7; **25**, 137898-15-8; **25** phenol derivative, 15969-08-1; **26c**, 137898-16-9; **27**, 137898-17-0; **27** phenol derivative, 2316-61-2; **28c**, 137898-18-1; **29**, 137898-19-2; **29** phenol derivative, 134-96-3; **30c**, 137898-20-5; **31**, 86364-02-5; **31** phenol derivative, 576-26-1; **32c**, 1587-05-9; **32g**, 137898-22-7; **34**, 137898-23-8; $PdCl_2(PPh_3)$32, 13965-03-2; $MeSnBu_3$, 594-27-4; $PhSnBu_3$, 960-16-7; $H_2C{=}CHCH_2SnBu_3$, 24850-33-7; $H_2C{=}CHSnBu_3$, 7486-35-3; $PhC{\equiv}CSnBu_3$, 3757-88-8; $BuSnBu_3$, 1461-25-2; $MeOC_6H_4$-*o*-$SnBu_3$, 86487-17-4.

**Supplementary Material Available:** $^1$H and $^{13}$C NMR spectra for compounds **2c**, **2g**, **4g**, **18c**, **22b**, **24c**, **28cc**, **31**, **32c**, **32g**, **33**, and **34** (24 pages). Ordering information is given on any current masthead page.