Regio- and Stereoselective Au(I)-Catalyzed Intermolecular Hydroalkoxylation of Aryl Allenes

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Abstract: In the presence of a catalytic amount of Ph_3PAuNO_3 and H_2SO_4, the hydroalkoxylation of allenes with alcohols has been shown to proceed smoothly and give allylic ethers in good yields and high regio- and stereoselectivity.

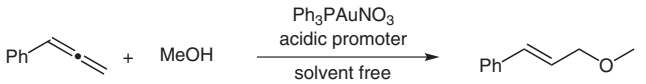
Key words: allenes, catalysis, alcohols, regioselectivity, stereoselectivity, hydroalkoxylation

Gold salts are powerful soft Lewis acids and readily promote reaction of unsaturated C–C bonds with a variety of nucleophiles for the formation of carbon–carbon and carbon–heteroatom bonds.[1–3] In the literature, a wide range of metal-catalyzed intramolecular hydroalkoxylation of allenes are known,[4] but only a few examples of intermolecular hydroalkoxylation of allenes have been disclosed.[5–7] Recently, Widenhoefer[6] and Yamamoto[7] independently reported the utility of cationic Au(I)–*N*-heterocyclic carbene or phosphine complex together with AgOTf as catalysts for intermolecular hydroalkoxylation of allenes. As part of our ongoing studies on metal-catalyzed atom-economical reactions, we have been interested in the use of gold compounds for simple and highly efficient transformations.[8] Herein we report that the Au(I)–sulfuric acid systems can serve as powerful catalysts, which promote the intermolecular hydroalkoxylation of allenes with high regio- and stereoselectivity.

The reaction of (propa-1,2-dienyl)benzene (**1a**, 0.5 mmol) with methanol (**2a**, 0.6 mmol) in the presence of a catalytic amount of PPh_3AuNO_3 (2 mol%) and concentrated sulfuric acid (5 mol%) at 40 °C proceeded efficiently to form allylic ether **3a** in 72% isolated yield with perfect regio- and stereoselectivity (Table 1, entry 7). Other possible isomers could not be detected. The reaction did not proceed in the absence of either the Au catalyst or sulfuric acid (Table 1, entries 2 and 10). Decreasing the amount of the Au catalyst or sulfuric acid resulted in a lower yield, and the addition of a large amount of them did not affect the reaction (Table 1, entries 5–8).

To further assess the scope of this process, we have examined the hydroalkoxylation of different allenes with alcohols under the optimized conditions as indicated in entry 7 of Table 1. The results are summarized in Table 2.[9] All reactions were run under solvent-free conditions. All primary alcohols could serve as good substrates to afford the corresponding allylic alcohols (Table 2, entries 1, 2, 5, and 7). Secondary and tertiary alcohols were also converted into the expected allylic ethers in good yields with perfect regio- and stereoselectivity (Table 2, entries 3, 4, 8, 11, 12, 15, 18). Benzyl alcohol also reacted efficiently (Table 2, entry 6). Allenes with an electron-donating alkyl group on the benzene ring gave good isolated yields of the corresponding allylic ethers (Table 2, entries 9–15). With a more electron-donating alkoxy group, the expected adducts were obtained in good yields (Table 2, entries 16–20). In addition, the hydroalkoxylation of allene bearing electron-withdrawing fluoro group on the benzene ring with ethanol also took place smoothly to show similar reactivity and selectivity (Table 2, entry 21). Hydroalkoxylation of 1,3-disubstituted allene **1g** gave the corresponding product as a single stereoisomer in good yield (Table 2, entry 22).

Table 1 Au-Catalyzed Hydroalkoxylation of Allenes **1a** with Alcohols **2a**[a]



1a **2a** **3a**

Entry	Ph_3PAuNO_3 (mol%)	H_2SO_4 (mol%)	Temp (°C)	Time (h)	Yield (%)[b]
1	0	0	70	20	0
2	5	0	40	20	0
3	5	0	70	20	0
4	5	20	40	9	69
5	5	5	40	3.5	70
6	5	2	40	8	52
7	2	5	40	4	72
8	1	5	40	10	48
9	2	5	70	6	61
10	0	5	40	8	trace

[a] All reactions were performed with 0.5 mmol of **1a**, 0.6 mmol of **2a**, 0–5 mol% of Ph_3PAuNO_3, and 0–20 mol% of acid.
[b] Isolated yields.

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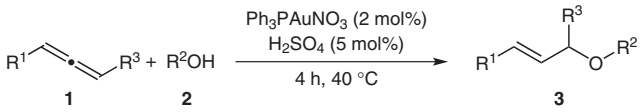
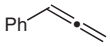
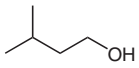
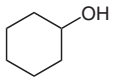
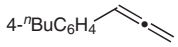
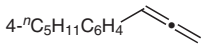
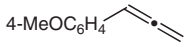
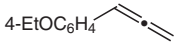
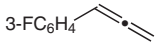
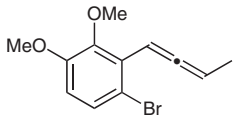
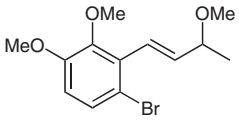
Table 2 Au-Catalyzed Hydroalkoxylation of Allenes **1** with Alcohols **2**[a]



1 2 3

Entry	Allene	Alcohol	Product	Yield (%)[b]
1		MeOH	**3a**	72
2		EtOH	**3b**	77
3		*i*-PrOH	**3c**	81
4		*t*-BuOH	**3d**	78
5	**1a**	*n*-$C_8H_{17}OH$	**3e**	79
6		BnOH	**3f**	82
7			**3g**	80
8			**3h**	86
9		MeOH	**3i**	83
10		EtOH	**3j**	85
11		*i*-PrOH	**3k**	85
12	**1b**	*t*-BuOH	**3l**	85
13		MeOH	**3m**	93
14		EtOH	**3n**	99
15	**1c**	*i*-PrOH	**3o**	93
16		MeOH	**3p**	85
17		EtOH	**3q**	75
18		*i*-PrOH	**3r**	81
19	**1d**	BnOH	**3s**	79
20		EtOH	**3t**	87
	1e			
21		EtOH	**3u**	77
	1f			
22		MeOH		84
	1g		**3v**	

[a] All reactions were performed with 0.5 mmol of **1**, 0.6 mmol of **2**, 2 mol% of PPh_3AuNO_3, and 5 mol% of acid at 40 °C for 4 h.
[b] Isolated yields.

In conclusion, we have developed an efficient method that uses PPh_3AuNO_3 and sulfuric acid that can catalyze the intermolecular hydroalkoxylation of allenes with different alcohols in good yields with high regio- and stereoselectivity without solvent. Further studies are currently under way in our laboratory.

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synlett.

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References and Notes

(1) Recent reviews, see: (a) Skouta, R.; Li, C.-J. *Tetrahedron* **2008**, *64*, 4917. (b) Shen, H. C. *Tetrahedron* **2008**, *64*, 3885. (c) Muzart, J. *Tetrahedron* **2008**, *64*, 3815. (d) Hashmi, A. S. K. *Chem. Rev.* **2007**, *107*, 3180. (e) Hashmi, A. S. K. *Gold Bull.* **2004**, *37*, 51. (f) Arcadi, A.; Di Giuseppe, S. *Curr. Org. Chem.* **2004**, *8*, 795.

(2) For examples, see: (a) Skouta, R.; Li, C. J. *Angew. Chem. Int. Ed.* **2007**, *46*, 1117. (b) Dube, P.; Toste, F. D. *J. Am. Chem. Soc.* **2006**, *128*, 12062. (c) Casado, R.; Contel, M.; Laguna, M.; Romero, P.; Sanz, S. *J. Am. Chem. Soc.* **2003**, *125*, 11925. (d) Gonzalez-Arellano, C.; Abad, A.; Corma, A.; Garcia, H.; Iglesias, M.; Sanchez, F. *Angew. Chem. Int. Ed.* **2007**, *46*, 1536. (e) Zhang, Z. B.; Widenhoefer, R. A. *Angew. Chem. Int. Ed.* **2007**, *46*, 283. (f) Hashmi, A. S. K.; Weyrauch, J. P.; Kurpejovi, E.; Frost, T. M.; Miehlich, B.; Frey, W.; Bats, J. W. *Chem. Eur. J.* **2006**, *12*, 5806. (g) LaLonde, R. L.; Sherry, B. D.; Kang, E. J.; Toste, F. D. *J. Am. Chem. Soc.* **2006**, *129*, 2452. (h) Mézailles, N.; Ricard, L.; Gagosz, F. *Org. Lett.* **2005**, *7*, 4133. (i) Mézailles, N.; Ricard, L.; Gagosz, F. *Org. Lett.* **2005**, *7*, 4133.

(3) (a) Genin, E.; Toullec, P. Y.; Antoniotti, S.; Brancour, C.; Genêt, J.-P.; Michelet, V. *J. Am. Chem. Soc.* **2006**, *128*, 3112. (b) Sun, J.; Conley, M. P.; Zhang, L.; Kozmin, S. A. *J. Am. Chem. Soc.* **2006**, *128*, 9705. (c) Sherry, B. D.; Maus, L.; Laforteza, B. N.; Toste, F. D. *J. Am. Chem. Soc.* **2006**, *128*, 8132. (d) Fukuda, Y.; Utimoto, K. *J. Org. Chem.* **1991**, *56*, 3729. (e) Fukuda, Y.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 203. (f) Mizushima, E.; Sato, K.; Hayashi, T.; Tanaka, M. *Angew. Chem. Int. Ed.* **2002**, *41*, 4563. (g) Roembke, P.; Schmidbaur, H.; Cronje, S.; Raubenheimer, H. *J. Mol. Catal. A: Chem.* **2004**, *212*, 35. (h) Mizushima, E.; Cui, D.-M.; Nath, D. C. D.; Hayashi, T.; Tanaka, M. *Org. Synth.* **2006**, *83*, 55. (i) Mizushima, E.; Sato, K.; Hayashi, T.; Tanaka, M. *Org. Lett.* **2003**, *5*, 3349.

(4) (a) Olsson, L.-I.; Claesson, A. *Synthesis* **1979**, 743. (b) Marshall, J. A.; Wolf, M. A.; Wallace, E. M. *J. Org. Chem.* **1997**, *62*, 367. (c) Deutsch, C.; Gockel, B.; Hoffmann-Röder, A.; Krause, N. *Synlett* **2007**, 1790. (d) Hamilton, G. L.; Kang, E. J.; Mba, M.; Toste, F. D. *Science* **2007**, *317*, 496. (e) Volz, F.; Krause, N. *Org. Biomol. Chem.* **2007**, *5*, 1519. (f) Hashmi, A. S. K.; Blanco, M. C.; Fischer, D.; Bats, J. W. *Eur. J. Org. Chem.* **2006**, 1387. (g) Erdsak, J.; Krause, N. *Synthesis* **2007**, 3741. (h) Alcaide, B.; Almendros, P.; Martinez del Campo, T. *Angew. Chem. Int. Ed.* **2007**, *46*, 6684. (i) Zhang, Z.; Liu, C.; Kinder, R. E.; Han, X.; Qian, H.; Widenhoefer, R. A. *J. Am. Chem. Soc.* **2006**, *128*, 9066. (j) Zhang, Z.; Widenhoefer, R. A. *Angew. Chem. Ind. Ed.* **2007**, *46*, 283. (k) Hoffmann-Röder, A.; Krause, N. *Org. Lett.* **2001**, *3*, 2537. (l) Gockel, B.; Krause, N. *Org. Lett.* **2006**, *8*, 4485. (m) Walkup, R. D.; Park, G. *Tetrahedron Lett.* **1987**, *28*, 1023. (n) Ma, S.; Yu, Z.; Wu, S. *Tetrahedron* **2001**, *57*, 1585. (o) Yu, X.; Seo, S.-Y.; Marks, T. J. *J. Am. Chem. Soc.* **2007**, *129*, 7244.

(5) (a) Fukuda, Y.; Utimoto, K. *J. Org. Chem.* **1991**, *56*, 3729. (b) Fukuda, Y.; Utimoto, K. JP 04095039, **1992**; *Chem. Abstr*. **1992**, *117*, 191330.

(6) Zhang, Z.; Widenhoefer, R. A. *Org. Lett.* **2008**, *10*, 2079.

(7) Nishina, N.; Yamamoto, Y. *Tetrahedron Lett.* **2008**, *49*, 1023.

(8) (a) Zhang, C.; Cui, D.-M.; Yao, L.-Y.; Wang, B.-S.; Hu, Y.-Z.; Hayashi, T. *J. Org. Chem.* **2008**, *73*, 7811. (b) Cui, D.-M.; Zheng, Z.-L.; Zhang, C. *J. Org. Chem.* **2009**, *74*, 1426. (c) Cui, D.-M.; Meng, Q.; Zheng, J.-Z.; Zhang, C. *Chem. Commun.* **2009**, DOI: 10.1039/b818863g.

(9) **Typical Experimental Procedure**

To a reactor containing allene (0.5 mmol), Ph_3PAuNO_3 (0.01 mmol), and alcohol (0.6 mmol) was added H_2SO_4 (0.025 mmol). The mixture was then sealed and stirred at 40 °C for 4 h. It was quenched with sat. soln of $NaHCO_3$ and then extracted with EtOAc (3 × 10 mL). The organic layer was washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by flash chromatography to give the pure product.

(*E*)-1-Butyl-4-(3-methoxyprop-1-enyl)benzene (3i)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.30 (d, *J* = 8.5 Hz, 2 H), 7.12 (d, *J* = 8.5 Hz, 2 H), 6.57 (d, *J* = 16.0 Hz, 1 H), 6.23 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.07 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.37 (s, 3 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 1.60–1.56 (m, 2 H), 1.37–1.32 (m, 2 H), 0.92 (t, *J* = 7.5 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.6, 134.1, 132.5, 128.6, 126.4, 124.9, 73.2, 57.9, 35.4, 33.5, 22.3, 13.9. IR: ν = 2950, 2929, 2958, 1635, 1512, 1456, 1384, 1191, 1119, 968, 847, 553 cm^{-1}. HRMS: *m/z* calcd for $C_{14}H_{20}O$ [M + 1$^+$]; 205.1592; found: 205.1591.

(*E*)-1-Butyl-4-(3-ethoxyprop-1-enyl)benzene (3j)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.80 (d, *J* = 8.0 Hz, 2 H), 7.12 (d, *J* = 8.0 Hz, 2 H), 6.57 (d, *J* = 16.0 Hz, 1 H), 6.26 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.12 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.54 (q, *J* = 7.0 Hz, 2 H), 2.59 (t, *J* = 7.5 Hz, 2 H), 1.60–1.55 (m, 2 H), 1.39–1.30 (m, 2 H), 1.24 (t, *J* = 7.0 Hz, 3 H), 0.92 (t, *J* = 7.5 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.5, 134.2, 132.3, 128.6, 126.4, 125.3, 71.4, 65.6, 35.4, 33.6, 22.4, 15.3, 14.0. IR: ν = 2928, 1636, 1508, 1384, 1095, 526 cm^{-1}. HRMS: *m/z* calcd for $C_{15}H_{22}O$ [M$^+$]: 218.1671; found: 218.1680.

(*E*)-1-Butyl-4-(3-isopropoxyprop-1-enyl)benzene (3k)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.29 (d, *J* = 8.0 Hz, 2 H), 7.11 (d, *J* = 8.0 Hz, 2 H), 6.55 (d, *J* = 16.0 Hz, 1 H), 6.26 (dt, *J* = 16.0, 6.5 Hz, 1 H), 4.12 (dd, *J* = 6.5, 1.5 Hz, 2 H), 3.71–3.63 (m, 1 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 1.63–1.55 (m, 2 H), 1.37–1.30 (m, 2 H), 1.20 (d, *J* = 6.0 Hz, 6 H), 0.92 (t, *J* = 7.5 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.5, 134.4, 131.9, 128.7, 126.5, 126.0, 70.9, 69.0, 35.5, 33.7, 22.5, 22.3, 14.1. IR: ν = 2932, 1614, 1558, 1515, 1456, 1384, 1247, 1156, 1137, 1029, 810, 749, 551 cm^{-1}. HRMS: *m/z* calcd for $C_{16}H_{24}O$ [M$^+$]: 232.1827; found: 232.1830.

(*E*)-1-(3-*tert*-Butoxyprop-1-enyl)-4-butylbenzene (3l)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.29 (d, *J* = 8.0 Hz, 2 H), 7.10 (d, *J* = 8.0 Hz, 2 H), 6.57 (d, *J* = 16.0 Hz, 1 H), 6.25 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.06 (dd, *J* = 6.0, 1.5 Hz, 2 H), 2.58 (t, *J* = 7.5 Hz, 2 H), 1.61–1.54 (m, 2 H), 1.36–1.31 (m, 2 H), 1.25 (s, 9 H), 0.92 (t, *J* = 7.5 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.2, 134.5, 131.2, 128.5, 126.6, 126.3, 73.3, 63.0, 35.4, 33.6, 27.7, 22.4, 14.0. IR: ν = 2958, 2929, 2858, 1681, 1625, 1512, 1457, 1384, 1194, 1122, 969, 525 cm^{-1}. HRMS: *m/z* calcd for $C_{17}H_{26}O$ [M$^+$]: 246.1984; found: 246.1989.

(*E*)-1-(3-Methoxyprop-1-enyl)-4-pentylbenzene (3m)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.30 (d, *J* = 8.5 Hz, 2 H), 7.12 (d, *J* = 8.5 Hz, 2 H), 6.57 (d, *J* = 16.0 Hz, 1 H), 6.23 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.06 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.37 (s, 3 H), 2.57 (t, *J* = 7.5 Hz, 2 H), 1.63–1.56 (m, 2 H), 1.34–1.29 (m, 4 H), 0.88 (t, *J* = 7.0 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.6, 134.1, 132.5, 128.6, 126.4, 124.9, 73.2, 57.8, 35.6, 31.5, 31.1, 22.5, 14.0. IR: ν = 2927,2855, 1634, 1384, 1124, 544 cm^{-1}. HRMS: *m/z* calcd for $C_{15}H_{22}O$ [M$^+$]: 218.1671; found: 218.1665.

(*E*)-1-(3-Ethoxyprop-1-enyl)-4-pentylbenzene (3n)

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.29 (d, *J* = 8.0 Hz, 2 H), 7.10 (d, *J* = 8.0 Hz, 2 H), 6.57 (d, *J* = 16.0 Hz, 1 H), 6.25 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.11 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.53 (q, *J* = 7.0 Hz, 2 H), 2.57 (t, *J* = 7.5 Hz, 2 H), 1.63–1.56 (m, 2 H), 1.33–1.30 (m, 4 H), 1.24 (t, *J* = 7.0 Hz, 3 H), 0.88 (t, *J* = 7.0 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.5, 134.2, 132.2, 128.6, 126.4, 125.3, 71.3, 65.6, 35.6, 31.5, 31.1, 22.5, 15.2, 14.0. IR: ν = 2950, 2927, 2855, 1652, 1558, 1506, 1456, 1384, 1100, 968, 539 cm^{-1}. HRMS: *m/z* calcd for $C_{16}H_{24}O$ [M$^+$]: 232.1831; found: 232.1827.

(*E*)-1-(3-Isopropoxyprop-1-enyl)-4-pentylbenzene (3o)
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.29 (d, *J* = 8.0 Hz, 2 H), 7.11 (d, *J* = 8.0 Hz, 2 H), 6.57 (d, *J* = 15.5 Hz, 1 H), 6.25 (dt, *J* = 15.5, 6.0 Hz, 1 H), 4.12 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.71–3.65 (m, 1 H), 2.57 (t, *J* = 7.5 Hz, 2 H), 1.63–1.56 (m, 2 H), 1.34–1.29 (m, 4 H), 1.20 (d, *J* = 6.0 Hz, 6 H), 0.88 (t, *J* = 7.0 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 142.4, 134.3, 131.8, 128.5, 126.4, 125.8, 70.8, 68.8, 35.6, 31.5, 31.1, 22.5, 22.1, 14.0. IR: ν = 2950, 2927, 2856, 1633, 1384, 1123, 1070, 965, 544 cm^{-1}. HRMS: *m/z* calcd for $C_{17}H_{26}O$ [M$^+$]: 246.1984; found: 246.1981.

(*E*)-1-(3-Isopropoxyprop-1-enyl)-4-methoxybenzene (3r)
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.33–7.31 (m, 2 H), 6.85–6.83 (m, 2 H), 6.54 (d, *J* = 15.5 Hz, 1 H), 6.17 (dt, *J* = 15.5, 6.0 Hz,1 H), 4.11 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.80 (s, 3 H), 3.71–3.65 (m, 1 H), 1.20 (d, *J* = 6.0 Hz, 6 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 159.2, 131.5, 129.7, 127.6, 124.6, 113.9, 70.8, 68.9, 55.3, 22.2. IR: ν = 2872, 1634, 1558, 1491, 1407, 1384, 1088, 1038, 1013, 937, 804, 485 cm^{-1}. HRMS: *m/z* calcd for $C_{13}H_{18}O$ [M + 1$^+$]: 207.1385; found: 207.1385.

(*E*)-1-(3-Ethoxyprop-1-enyl)-3-fluorobenzene (3u)
^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.28–7.24 (m, 1 H), 7.15–7.13 (m, 1 H), 7.10–7.06 (m, 1 H), 6.94–6.90 (m, 1 H), 6.58 (d, *J* = 16.0 Hz, 1 H), 6.30 (dt, *J* = 16.0, 6.0 Hz, 1 H), 4.14 (dd, *J* = 6.0, 1.5 Hz, 2 H), 3.56 (q, *J* = 7.0 Hz, 2 H), 1.25 (t, *J* = 7.0 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 163.1 (d, *J* = 243.8 Hz), 139.2 (d, *J* = 8.8 Hz), 130.8, 129.9 (d, *J* = 8.8 Hz), 127.8, 122.3, 114.3 (d, *J* = 21.3 Hz), 112.9 (d, *J* = 21.3 Hz), 70.9, 65.9, 15.2. IR: ν = 2995, 1770, 1759, 1635, 1834, 1246, 1058, 913, 743, 526 cm^{-1}. HRMS: *m/z* calcd for $C_{11}H_{13}FO$ [M$^+$]: 180.0950; found: 180.0946.

(*E*)-1-Bromo-3,4-dimethoxy-2-(3-methoxybut-1-enyl)-benzene (3v)
^{1}H NMR (500MHz, $CDCl_3$): δ = 7.29 (d, *J* = 8.5 Hz, 2 H), 6.70 (d, *J* = 8.5 Hz, 2 H), 6.48 (d, *J* = 16.0 Hz, 1 H), 6.14 (dd, *J* = 16.0, 7.5 Hz, 1 H), 3.95–3.90 (m, 1 H), 3.86 (s, 3 H), 3.75 (s, 3 H), 3.38 (s, 3 H), 1.36 (dd, *J* = 6.5, 2.5 Hz, 3 H). ^{13}C NMR (125 MHz, $CDCl_3$): δ = 152.6, 148.1, 138.8, 131.2, 128.1, 125.9, 114.6, 112.1, 78.7, 60.1, 56.2, 56.0, 21.6. IR: ν = 2928, 1636, 1508, 1384, 1095, 526 cm^{-1}. HRMS: *m/z* calcd for $C_{13}H_{17}BrO_3$ [M$^+$]: 300.0361; found: 300.0341.