EurJOC European Journal of Organic Chemistry

FULL PAPER

DOI: 10.1002/ejoc.201500633

Base-Induced Cyclization of Propargyl Alkenylsulfones: A High-Yielding Synthesis of 4,5-Disubstituted 2*H*-Thiopyran 1,1-Dioxides

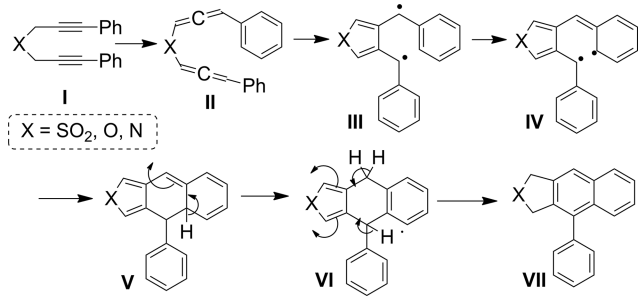
Ishita Hatial,[a][‡] Joyee Das,[a][‡] Ananta K. Ghosh,[b] and Amit Basak*[a]

Keywords: Sulfur heterocycles / Cyclization / Electrocyclic reactions / Alkynes / Allylic compounds

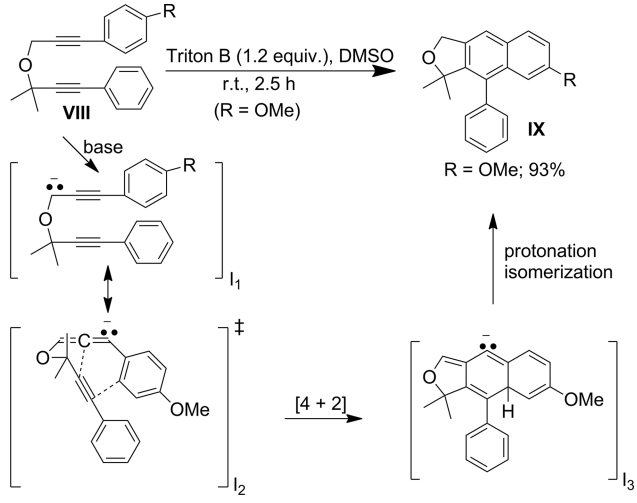
A convenient synthesis of 4,5-disubstituted 2*H*-thiopyran 1,1-dioxides is reported through a base induced process starting from eneyne sulfones. Except for strongly electron-withdrawing groups, the reaction tolerated a wide variety of substituents in the two aryl rings. This finding represents a major departure from the behaviour of the corresponding ethers. The reaction most probably proceeds through a 6π-electrocyclization from an in-situ-generated 1,3,5-trienyl sulfinate.

Introduction

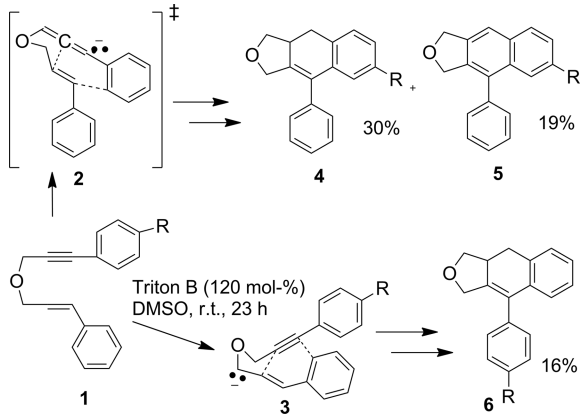
The reactivity of bispropargyl sulfones, ethers, and sulfonamides has been well studied, especially in recent years.[1] The reaction leads to the formation of two C–C bonds in high yield under mild conditions, and is popularly known as the Garratt–Braverman (GB) cyclization.[2] The synthetic utility of the reaction has recently been reported in a series of papers.[3] Although doubts remain about the exact mechanism of the reaction, a diradical mechanism involving a bis-allene intermediate (Scheme 1), as proposed initially by Garratt and Braverman and later supported by computations and selectivity profiles,[4] is the generally accepted one. In 2007, while studying the rearrangement of ethers, Kudoh et al.[5] proposed an anionic intramolecular Diels–Alder mechanism involving a monoallenyl anion (Scheme 2); this mechanism has the support of deuterium-labelling experiments as well as computations based on the HUMO–LUMO gap. The same authors also used the intramolecular Diels–Alder reaction mechanism to explain the selectivity of the cyclization of propargyl alkenyl ethers, which, upon treatment with a suitable base, generate products following a similar pathway (Scheme 3). Because of the



Scheme 1. Mechanism proposed by Garratt and Braverman.



Scheme 2. Mechanism proposed by Kudoh et al.



Scheme 3. Reaction with eneyne–ether system, as reported by Kudoh et al.[5]

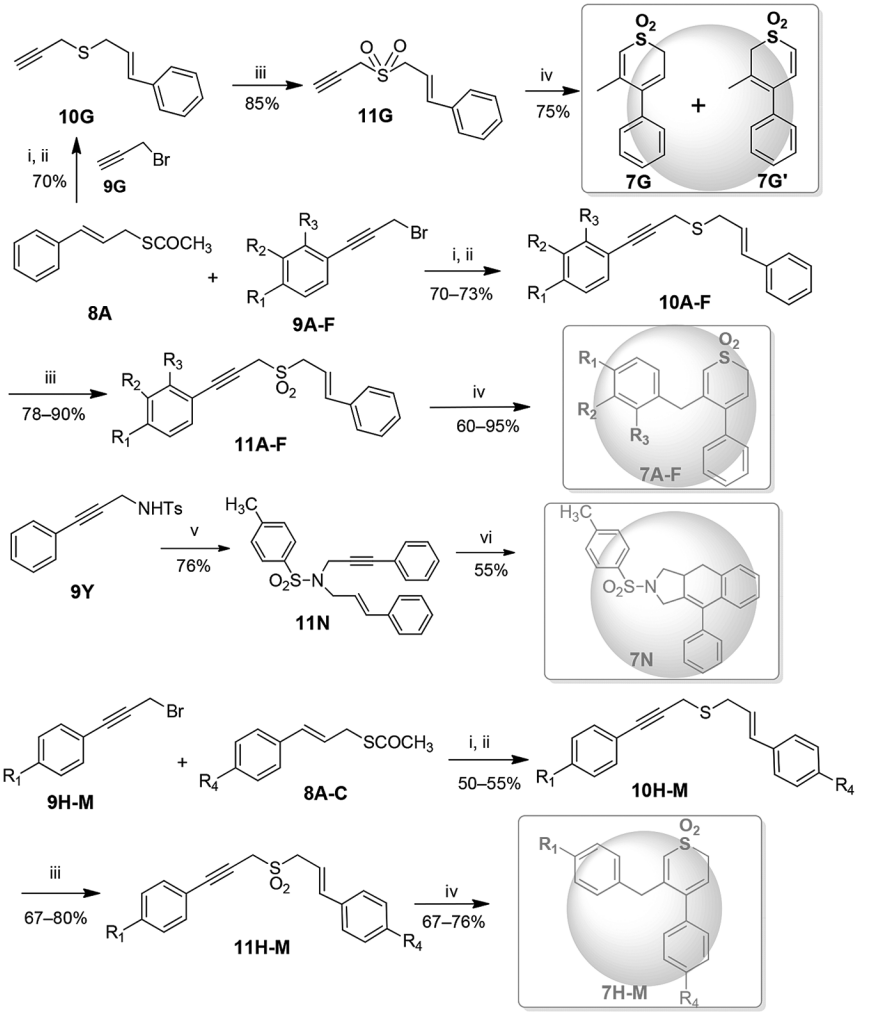
[a] Department of Chemistry, Indian Institute of Technology, Kharagpur 721302, India
E-mail: absk@chem.iitkgp.ernet.in
http://www.chemistry.iitkgp.ac.in/~absk/
http://www.iitkgp.ac.in/
[b] Department of Biotechnology, Indian Institute of Technology, Kharagpur 721302, India
[‡] Equal contribution
Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/ejoc.201500633.

reported differences between the reactivity and selectivity profiles of bis-propargyl sulfones vis-à-vis ethers,[6] we became curious to know whether similar products would be obtained when propargyl alkenyl sulfones were treated with base. With this idea in mind, we synthesized several propargyl alkenyl sulfones **11A**–**11M**. On treatment with a base (NaH/DMSO), these sulfones gave disubstituted thiopyran 1,1-dioxides **7A**–**7M**, instead of the aryl(dihydro)naphthalenes as was observed for the corresponding ethers. This method offers a convenient procedure for the synthesis of thiopyran dioxide derivatives with a variety of substituents, which are reported to be important in medicinal[7] and materials chemistry.[8] It has also been reported that that cyclic sulfones are attractive options for medicinal chemistry.[9] In this article, we describe our results along with possible mechanistic descriptions. A rationale for the differences in the reactivity profiles of sulfones and ethers is also provided.

Results and Discussion

The starting propargyl alkenyl sulfones (i.e., **11A**–**11M**) were prepared by the sequence of steps shown in Scheme 4. The key step was a K_2CO_3-mediated *S*-alkylation[10] of an alkenyl thiol, generated in situ from the corresponding thioacetate[11] **8A**–**8C**, with a propargyl bromide **9A**–**9M** (all the bromides are reported in the literature[4,12]). Subsequent oxidation of the crude sulfides (i.e., **10A**–**10M**) gave the target sulfones (i.e., **11A**–**11M**), which were isolated pure by chromatography. Sulfonamide **11N** was prepared by *N*-alkylation of phenyl propargylamine *p*-toluenesulfonamide derivative **9Y** with cinnamyl bromide.

The reactivity of the sulfones under basic conditions was then probed, starting with compound **11A**. Initial attempts to induce cyclization by treatment with Et_3N (catalytic or 1 equiv.) at room temp. failed. The use of stronger bases like DBU or DBN did not lead to cyclization, even at elevated temperatures; only decomposition of the starting material

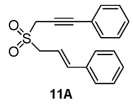
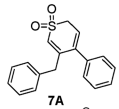
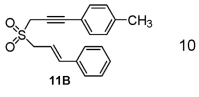
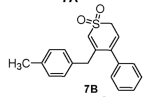
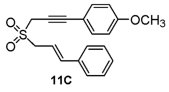
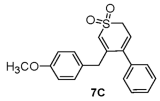
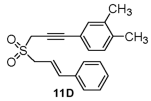
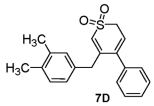
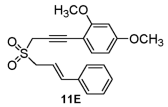
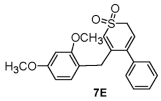
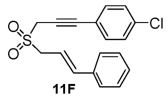
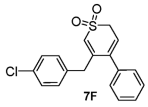
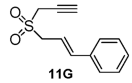
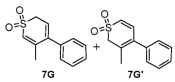
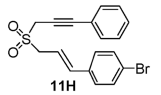
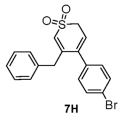
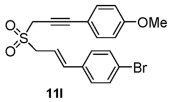
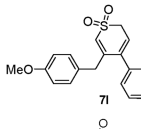
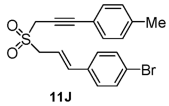
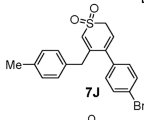
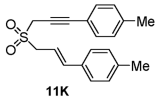
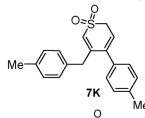
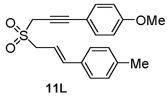
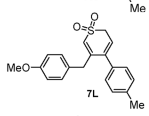
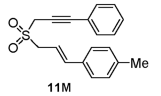
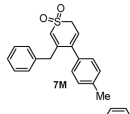
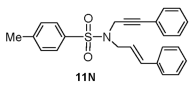
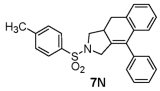
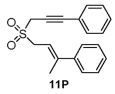


For **A** R_1 = H, R_2 = H,R_3=H, For **B** R_1 = CH_3, R_2 = H, R_3 =H , For **C** R_1 = OMe, R_2 = H, R_3 = H, For **D** R_1 = CH_3, R_2 = CH_3, R_3 = H, For **E** R_1 = R_3 = OMe, R_2 = H, **F** R_1 =Cl, R_2 = H, R_3 = H, For **H** R_1 =H, R_4 = Br, For **I** R_1 = OMe, R_4 = Br, For **J** R_1 = Me, R_4 = Br, For **K** R_1 = R_4 = Me, For **L** R_1 = OMe, R_4 = Me, For **M** R_1 = H, R_4 = Me

i: K_2CO_3 (5 equiv.), MeOH, 0 to 20 °C, 4h; ii: added **9A-M** (1 equiv.) ; iii: Oxone (2.5 equiv.), THF/water(1:1), 0 °C to r.t., 12 h; iv: NaH (1.2 equiv.), DMSO, ice-cold, 10 min; v: cinnamyl bromide (1 equiv.), DMF, K_2CO_3 (3 equiv.), r.t., 18 h; vi: DBU (3 equiv.), toluene, reflux, 6 h

Scheme 4. Synthesis of propargyl alkenyl sulfones.

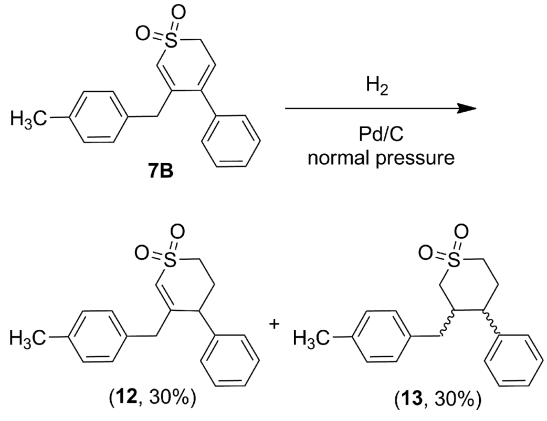
Table 1. Base-catalysed cyclization of propargyl alkenyl sulfones.

Entry	Substrate	Reaction time	Product	Yield
1	 11A	10 min[a]	 7A	75
2	 11B	10 min[a]	 7B	85
3	 11C	10 min[a]	 7C	90
4	 11D	10 min[a]	 7D	88
5	 11E	5 min[a]	 7E	95
6	 11F	15 min[a]	 7F	60
7	 11G	2 h[a]	 7G 7G'	75
8	 11H	10 min[a]	 7H	65
9	 11I	5 min[a]	 7I	70
10	 11J	5 min[a]	 7J	75
11	 11K	5 min[a]	 7K	67
12	 11L	5 min[a]	 7L	69
13	 11M	5 min[a]	 7M	76
14	 11N	6 h[b]	 7N	55
15[c]	 11P	5 min[a]	decomp.	–

[a] NaH/ DMSO, ice-cold. [b] DBU, toluene, reflux. [c] Sulfone **11P** was prepared by *S*-alkylation of phenylpropargylthiol, generated from the corresponding thioacetate, with β-methyl-substituted cinnamyl bromide.

was observed. Gratifyingly, upon treatment with NaH in DMSO at ice-cold temperature for 10 min, the sulfone underwent a clean reaction to give a single product, which was isolated pure by chromatography. Analysis by NMR spectroscopy and mass spectrometry confirmed the structure as 5-benzyl-4-phenyl-2*H*-thiopyran 1,1-dioxide (**7A**). The experiment was repeated with other sulfones, which also gave thiopyran-1,1-dioxide derivatives in decent yields. The results summarized in Table 1 show that the reactions of the alkenyl propargyl sulfones do not follow a GB pathway like the corresponding ethers. Rather, the reaction takes a different route involving the formation of only one new C–C bond to produce the thiopyran derivatives. The reaction is quite general, and it tolerated a large number of substituents on the phenyl rings of both the alkyne part as well as the cinnamoyl moiety; the yields ranged from moderate to excellent. Regarding the use of an electron-withdrawing aromatic system in the alkyne unit, we obtained the desired product only for a *p*-chloro-substituted (mildly withdrawing) derivative.[13] We wanted to study systems with more strongly electron-withdrawing groups like nitro and cyano. However, we were unable to synthesize the mixed sulfide of the nitro derivative, despite trying different reaction conditions. For the cyano derivative we could successfully synthesize the sulfone, but the cyclization reaction did not work; the starting material decomposed. The feasibility of the reaction was also investigated by using solvents of different polarities. The reaction failed to proceed in nonpolar solvents like dichloromethane, but it did work in moderately polar solvents like THF to give similar yields. While carrying out the reaction in THF, we isolated exomethylene compound **25** (structure confirmed by X-ray crystallography) from the reaction of **11G**. Interestingly, the corresponding sulfonamide (i.e., **11N**) followed the GB pathway like its ether counterpart to give aryl dihydronaphthalene derivative **7N**.

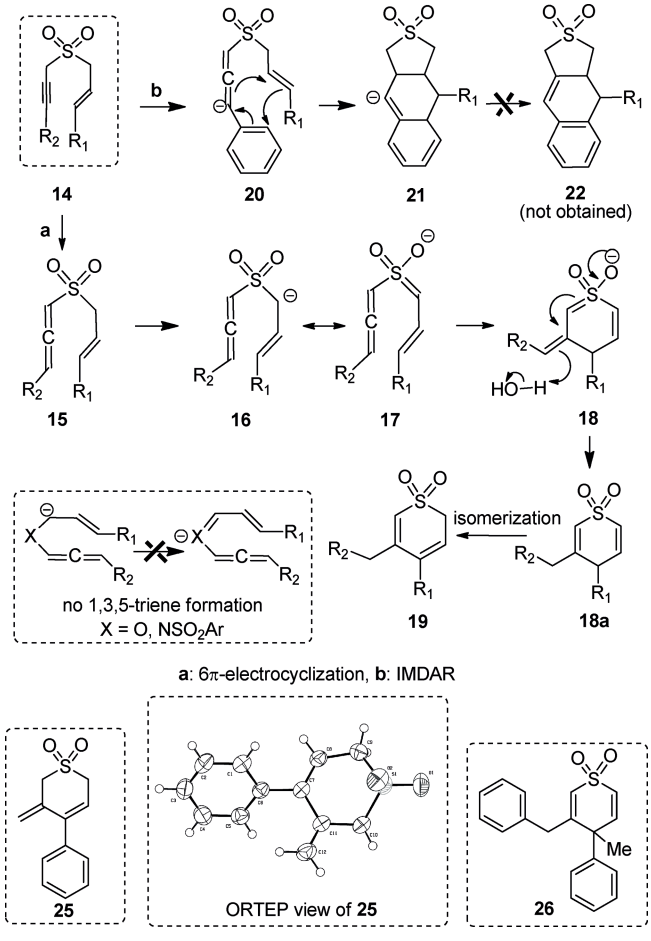
Thiopyran derivatives have been reported[14] to be fully hydrogenated under atmospheric pressure in the presence of Pd/C (10%) catalyst in methanol to give the corresponding saturated tetrahydrothiopyran 1,1-oxides. Following that procedure, thiopyran 1,1-dioxide **7B** was subjected to hydrogenation, which gave rise to a mixture of products (Scheme 5).



Scheme 5. Hydrogenation of 5-(4-methylbenzyl)-4-phenyl-2*H*-thiopyran 1,1-dioxide.

Fractional crystallization of the crude mixture produced a white solid, which was identified as dihydrothiopyran derivative **12**, obtained by incomplete but selective hydrogenation. The mother liquor contained an inseparable mixture of *cis*- and *trans*-tetrahydrothiopyran 1,1-oxides. Both the partially saturated and fully saturated skeletons are known to have biological activities.[15]

Regarding the mechanism, we believe that the reaction proceeds by an exothermic 6π-electrocyclization[16] process (Scheme 6, path a). The 1,3,5-triene framework required for the electrocyclization is produced by propargyl–allene isomerization followed by sulfinate generation. It appears that the 6π-electrocyclization is easier than the intramolecular Diels–Alder mechanism (Scheme 6, path b) unless the triene generation is not possible. This is consistent with the inability of the ether or sulfonamide to undergo a similar process. In these cases, the allylic anion cannot generate a 1,3,5-triene system, thus ruling out the 6π-electrocyclization process (see inset, Scheme 6). Hence the alternative GB-like process occurs for these systems. It may be mentioned here that although there is controversy regarding the nature of sulfone moiety, i.e., whether it is electron-withdrawing or -delocalizing, the involvement of such a sulfinate formation through electron delocalization has been reported in the literature.[17] The proposed mechanism is supported by the isolation of exomethylene derivative **25**, which could have been generated by 1,3-protonation after the electrocyclization. We carried out the reaction in deuterated solvents. Unfortunately, we were unable to reproduce the reaction in the deuterated protic solvent [D_4]methanol. However, when the reaction was repeated in [D_6]DMSO/NaH and quenched with water (H_2O), no incorporation of deuterium into the product could be observed, as revealed by ^{1}H NMR spectroscopy. The reaction was next carried out in the presence of [D_6]DMSO/NaH and quenched with D_2O. This time we obtained a product with complete deuterium incorporation at the benzylic CH_2 and at the CH_2 group adjacent to the sulfone moiety. However, as the product itself undergoes deuterium exchange at these two positions when treated with [D_6]DMSO/NaH and subsequent quenching with D_2O, the deuterium-labelling experiments remain inconclusive regarding the mechanistic pathway (all relevant NMR spectra are included in the Supporting Information). We also checked the reactivity of β-methyl cinnamyl derivative **11P**, hoping to isolate intermediate **26**. However, the reaction failed to produce any well-defined product.



Scheme 6. Proposed 6π-electrocyclization-based mechanism (IMDAR = intramolecular Diels–Alder reaction).

Conclusion

A new high-yielding method for the synthesis of disubstituted 2*H*-thiopyran 1,1-dioxide has been developed, starting from propargyl alkenyl sulfones. A 6π-electrocyclization mechanism for the reaction has been proposed that also explains the inability of the corresponding ethers or sulfonamides to undergo a similar reaction. The synthesized thiopyran derivatives will be screened for biological activity in the future.

Experimental Section

General Remarks: ^{1}H ^{13}C NMR spectra were obtained with 200, 400, and 600 MHz Bruker NMR instruments, using [D]chloroform and [D_3]acetonitrile as solvents. The following abbreviations are used to describe peak patterns where appropriate: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br. = broad signal. All coupling constants (*J*) are given in Hz. Mass spectra were recorded in ESI$^+$ mode (ion trap).

General Procedure for Sulfonation. Synthesis of Compounds 11A–11P: Oxone (767 mg, 2.5 equiv.) was added to an ice-cold solution of crude sulfide **10A**–**10P** (1 mmol) in THF/H_2O (1:1; 20 mL), and the mixture was stirred at room temperature under a nitrogen atmosphere. After 12 h, the reaction mixture was diluted with dichloromethane, and the organic layer was washed with brine, and dried with anhydrous sodium sulfate. The solvent was removed, and the crude residue was purified by column chromatography (silica gel, petroleum ether/ethyl acetate mixture as eluent).

Selected Spectroscopic Data

4-[3-(3-Phenylprop-2-ene-1-sulfonyl)prop-1-ynyl]benzene (11A): White gummy mass (252 mg, 85%). IR (neat): $\tilde{\nu}$ = 3056, 2920, 2850, 2235, 1623, 1447, 1301, 1121, 750 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.52–7.31 (m, 10 H), 6.83 (d, *J* = 15.9 Hz, 1 H), 6.32 (dt, *J* = 15.6, 7.6 Hz, 1 H), 4.12 (d, *J* = 7.8 Hz, 4 H)

ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 139.9, 135.8, 132.3, 129.6, 129.1, 128.8, 127.1, 121.9, 115.1, 88.2, 77.9, 56.1, 44.9 ppm. HRMS: calcd. for $C_{18}H_{17}O_2S^+$ [M + H]$^+$ 297.0944; found 297.0945.

1-Methyl-4-[3-(3-phenylprop-2-ene-1-sulfonyl)prop-1-ynyl]benzene (11B): White solid (279 mg, 90%), m.p. 111–112 °C. IR (neat): $\tilde{\nu}$ = 3058, 2927, 2851, 2240, 1620, 1445, 1309, 750 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.44–7.31 (m, 7 H), 7.16 (d, J = 8.0 Hz, 2 H), 6.83 (d, J = 15.9 Hz, 1 H), 6.30 (dt, J = 15.6, 7.6 Hz, 1 H), 4.11 (d, J = 7.6 Hz, 2 H), 4.08 (s, 2 H), 2.38 (s, 3 H) ppm. ^{13}C NMR (50 MHz, [D]chloroform): δ = 139.8, 135.6, 132.0, 129.9, 129.4, 128.9, 126.9, 118.6, 114.9, 88.3, 75.9, 55.7, 44.7, 21.7 ppm. HRMS: calcd. for $C_{19}H_{19}O_2S^+$ [M + H]$^+$ 311.1100; found 311.1090.

1-Methoxy-4-[3-(3-phenylprop-2-ene-1-sulfonyl)prop-1-ynyl]benzene (11C): Yellow sticky mass (277 mg, 85%). IR (neat): $\tilde{\nu}$ = 3056, 2926, 2855, 2227, 1605, 1513, 1444, 1306, 1178, 1030, 743 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43–7.25 (m, 8 H), 6.87 (d, J = 8.2 Hz, 2 H), 6.58 (d, J = 16 Hz, 1 H), 6.25 (dt, J = 15.3, 7.5 Hz, 1 H), 3.81 (d, J = 3.7 Hz, 3 H), 3.55 (d, J = 7.7 Hz, 2 H), 3.48 (s, 2 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 160.4, 139.7, 135.6, 133.6, 128.9, 128.8, 126.9, 114.9, 114.2, 113.6, 88.2, 75.1, 55.7, 55.4, 44.7 ppm. HRMS: calcd. for $C_{19}H_{19}O_3S^+$ [M + H]$^+$ 327.1049; found 327.1046.

1,2-Dimethyl-4-[3-(3-phenylprop-2-ene-1-sulfonyl)prop-1-ynyl]benzene (11D): Off-white solid (253 mg, 78%), m.p. 86–87 °C. IR (neat): $\tilde{\nu}$ = 3059, 2921, 2849, 2234, 1620, 1445, 1306, 1122, 753 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43 (d, J = 7.4 Hz, 2 H), 7.35 (q, J = 9.1, 7.9 Hz, 3 H), 7.29–7.20 (m, 2 H), 7.11 (d, J = 7.7 Hz, 1 H), 6.84 (d, J = 15.8 Hz, 1 H), 6.31 (dt, J = 15.5, 7.6 Hz, 1 H), 4.11 (d, J = 7.6 Hz, 2 H), 4.08 (s, 2 H), 2.29 (s, 3 H), 2.26 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 139.9, 138.6, 137.1, 135.7, 133.12, 129.9, 129.6, 129.0, 128.9, 127.0, 118.9, 115.1, 88.6, 75.7, 55.8, 44.9, 29.9, 20.0, 19.8 ppm. HRMS: calcd. for $C_{20}H_{21}O_2S^+$ [M + H]$^+$ 325.1257; found 325.1247.

2,4-Dimethoxy-1-[3-(3-phenylprop-2-ene-1-sulfonyl)prop-1-ynyl]-benzene (11E): Yellow solid (299 mg, 84%), m.p. 97–98 °C. IR (neat): $\tilde{\nu}$ = 3082, 2970, 2921, 2836, 2220, 1609, 1312, 1161, 1125, 1050, 723 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43–7.26 (m, 6 H), 6.95 (d, J = 15.9 Hz, 3 H), 6.47 (d, J = 7.7 Hz, 2 H), 6.32 (dt, J = 15.7, 7.8 Hz, 1 H), 4.19 (d, J = 7.8 Hz, 2 H), 4.09 (s, 2 H), 3.90 (s, 3 H), 3.87 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 162.2, 162.1, 139.8, 135.9, 134.8, 128.9, 127.0, 115.4, 105.2, 103.5, 98.7, 85.1, 79.3, 55.9, 55.7, 55.1, 44.9 ppm. HRMS: calcd. for $C_{20}H_{21}O_4S^+$ [M + H]$^+$ 357.1155; found 357.1144.

1-Chloro-4-[3-(3-phenylprop-2-ene-1-sulfonyl-1-ynyl)]benzene (11F): White gummy mass (248 mg, 75%). IR (neat): $\tilde{\nu}$ = 2950, 2867, 2237, 1635, 1456, 1313, 1121, 810, 752 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43–7.26 (m, 9 H), 6.81 (d, J = 15.8 Hz, 1 H), 6.30 (dt, J = 15.4, 7.6 Hz, 1 H), 4.10 (d, J = 7.4 Hz, 4 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 139.9, 135.6, 135.6, 133.4, 129.1, 129.1, 129.0, 128.8, 127.0, 120.2, 114.9, 87.1, 77.0, 56.3, 44.7 ppm. HRMS: calcd. for $C_{18}H_{16}ClO_2S^+$ [M + H]$^+$ 331.0554; found 331.0544.

[3-(Prop-2-yne-1-yne-sulfonyl)propenyl]benzene (11G): Pale yellow solid (187 mg, 85%), m.p. 74–75 °C. IR (neat): $\tilde{\nu}$ = 3270, 3053, 2921, 2135, 1510, 1418, 1303, 1125, 760 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43 (d, J = 7.2 Hz, 2 H), 7.34 (dq, J = 14.0, 7.0 Hz, 3 H), 6.81 (d, J = 15.9 Hz, 1 H), 6.25 (dt, J = 15.7, 7.7 Hz, 1 H), 4.08 (d, J = 7.6 Hz, 2 H), 3.85 (d, J = 2.2 Hz, 2 H), 2.58 (t, J = 2.5 Hz, 1 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 140.0, 135.6, 129.1, 129.0, 128.9, 127.0, 114.8, 76.96, 76.94, 76.90, 71.8, 55.6, 43.4 ppm. HRMS: calcd. for $C_{12}H_{13}O_2S^+$ [M + H]$^+$ 221.0631; found 221.0648.

(*E*)-1-Bromo-4-[3-(3-phenylprop-2-ynylsulfonyl)prop-1-enyl]benzene (11H): Yellow solid (300 mg, 80%), m.p. 94–95 °C. IR (neat): $\tilde{\nu}$ = 3045, 2967, 2245, 1635, 1445, 1312, 755, 550 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.49 (d, J = 12 Hz, 3 H), 7.43–7.40 (m, 1 H), 7.38–7.35 (m, 2 H), 7.30 (d, J = 12 Hz, 2 H), 7.28 (s, 1 H), 6.78 (d, J = 18 Hz, 1 H), 6.32 (dt, J = 18, 6 Hz, 1 H), 4.12 (d, J = 6 Hz, 2 H), 4.11 (s, 2 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 138.5, 134.4, 131.9, 129.3, 128.5, 128.3, 122.8, 121.4, 115.6, 88.15, 76.4, 55.7, 44.8 ppm. HRMS: calcd. for $C_{18}H_{16}BrO_2S^+$ [M + H]$^+$ 375.0054; found 375.0060.

(*E*)-1-Bromo-4-{3-[3-(4-methoxyphenyl)prop-2-ynylsulfonyl]prop-1-enyl}benzene (11I): Pale yellow solid (282 mg, 70%), m.p. 145–146 °C. IR (neat): $\tilde{\nu}$ = 3087, 2975, 2950, 2835, 2219, 1610, 1313, 1159, 1130, 1050, 725, 575 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.49 (d, J = 8.4 Hz, 2 H), 7.41 (d, J = 9 Hz, 2 H), 7.30 (d, J = 8.4 Hz, 2 H), 6.88 (d, J = 9 Hz, 2 H), 6.78 (d, J = 16.2 Hz, 1 H), 6.32 (dt, J = 16.2, 6 Hz, 1 H), 4.12 (d, J = 6 Hz, 2 H), 4.09 (s, 2 H), 3.85 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 160.4, 138.4, 134.4, 133.5, 131.9, 128.3, 122.8, 115.7, 114.2, 113.4, 88.2, 75.0, 55.6, 55.4, 44.9 ppm. HRMS: calcd. for $C_{19}H_{18}BrO_3S^+$ [M + H]$^+$ 405.0160; found 405.0167.

(*E*)-1-Bromo-4-[3-(3-*p*-tolylprop-2-ynylsulfonyl)prop-1-enyl]benzene (11J): White solid (291 mg, 75%), m.p. 180–181 °C. IR (neat): $\tilde{\nu}$ = 3077, 2974, 2850, 2220, 1659, 1440, 1323, 1126, 752, 560 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.49 (d, J = 8.4 Hz, 2 H), 7.38 (d, J = 7.8 Hz, 2 H), 7.30 (d, J = 8.4 Hz, 2 H), 7.18 (d, J = 7.8 Hz, 2 H), 6.77 (d, J = 15.6 Hz, 1 H), 6.32 (dt, J = 15.6, 6 Hz, 1 H), 4.12 (d, J = 6 Hz, 2 H), 4.09 (s, 2 H), 2.40 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 139.7, 138.4, 134.4, 131.9, 131.8, 129.2, 128.3, 122.8, 118.3, 115.6, 88.4, 75.7, 55.6, 44.9, 21.6 ppm. HRMS: calcd. for $C_{19}H_{18}BrO_2S^+$ [M + H]$^+$ 389.0211; found 389.0217.

(*E*)-1-Methyl-4-[3-(3-*p*-tolylallylsulfonyl)prop-1-ynyl]benzene (11K): Off-white solid (217 mg, 67%), m.p. 157–158 °C. IR (neat): $\tilde{\nu}$ = 3075, 2956, 2850, 2221, 1620, 1445, 1363, 1128, 753 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.40 (d, J = 7.8 Hz, 2 H), 7.34 (d, J = 7.2 Hz, 2 H), 7.18 (d, J = 7.8 Hz, 4 H), 6.82 (d, J = 16.2 Hz, 1 H), 6.26 (dt, J = 16.2, 7.2 Hz, 1 H), 4.12 (d, J = 7.2 Hz, 2 H), 4.09 (s, 2 H), 2.40 (s, 3 H), 2.38 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 139.6, 139.5, 138.9, 132.7, 131.9, 129.5, 129.2, 126.8, 118.5, 113.7, 88.2, 75.8, 55.7, 44.5, 21.6, 21.3 ppm. HRMS: calcd. for $C_{20}H_{21}O_2S^+$ [M + H]$^+$ 325.1262; found 325.1269.

(*E*)-1-Methoxy-4-[3-(3-*p*-tolylallylsulfonyl)prop-1-ynyl]benzene (11L): Pale yellow solid (245 mg, 72%), m.p. 115–116 °C. IR (neat): $\tilde{\nu}$ = 3078, 2925, 2235, 1656, 1456, 1320, 1125, 1055, 753 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.44 (d, J = 9 Hz, 2 H), 7.32 (d, J = 7.8 Hz, 2 H), 7.18 (d, J = 7.8 Hz, 2 H), 6.89 (d, J = 8.4 Hz, 2 H), 6.81 (d, J = 15.6 Hz, 1 H), 6.26 (dt, J = 15.6, 7.8 Hz, 1 H), 4.11 (d, J = 7.8 Hz, 2 H), 4.08 (s, 2 H), 3.85 (s, 3 H), 2.38 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 160.3, 139.6, 138.9, 133.5, 132.8, 129.5, 126.8, 114.1, 113.7, 113.6, 88.0, 75.1, 55.7, 55.4, 44.5, 21.3 ppm. HRMS: calcd. for $C_{20}H_{21}O_3S^+$ [M + H]$^+$ 341.1211; found 341.1213.

(*E*)-1-Methyl-4-[3-(3-phenylprop-2-ynylsulfonyl)prop-1-enyl]benzene (11M): Off-white solid (239 mg, 77%), m.p. 110–111 °C. IR (neat): $\tilde{\nu}$ = 3045, 2937, 2878, 2234, 1630, 1456, 1312, 1125, 750 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.50 (d, J =

8.4 Hz, 2 H), 7.43–7.34 (m, 5 H), 7.18 (d, J = 7.8 Hz, 2 H), 6.82 (d, J = 15.6 Hz, 1 H), 6.27 (dt, J = 15.6, 7.2 Hz, 1 H), 4.12 (d, J = 7.8 Hz, 2 H), 4.10 (s, 2 H), 2.38 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 139.6, 139.0, 132.7, 132.0, 129.5, 129.3, 128.5, 126.8, 121.6, 113.7, 88.0, 76.5, 55.8, 44.4, 21.3 ppm. HRMS: calcd. for $C_{19}H_{19}O_2S^+$ $[M + H]^+$ 311.1106; found 311.1108.

4-Methyl-*N*-(3-phenyl-allyl)-*N*-(3-phenylprop-2-ynyl)benzenesulfonamide (11N): White solid (305 mg, 76%) m.p. 89–90 °C. IR (neat): $\tilde{\nu}$ = 3056, 3039, 2928, 2852, 2247, 1605, 1445, 1345, 1322, 1158, 766 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.83 (d, J = 8.0 Hz, 2 H), 7.31 (dq, J = 31.3, 7.3 Hz, 10 H), 7.10 (d, J = 6.9 Hz, 2 H), 6.63 (d, J = 15.8 Hz, 1 H), 6.18 (dt, J = 14.2, 6.8 Hz, 1 H), 4.36 (s, 2 H), 4.08 (d, J = 6.7 Hz, 2 H), 2.36 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 143.8, 136.4, 136.3, 135.1, 131.7, 129.8, 128.8, 128.7, 128.3, 128.1, 126.8, 123.4, 122.4, 86.1, 82.1, 49.2, 37.1, 21.7 ppm. HRMS: calcd. for $C_{25}H_{24}NO_2S^+$ $[M + H]^+$ 402.1522; found 402.1518.

(*E*)-[3-(3-Phenylbut-2-enylsulfonyl)prop-1-ynyl]benzene (11P): Yellow liquid (186 mg, 60%). IR (neat): $\tilde{\nu}$ = 3055, 2928, 2855, 2243, 1623, 1447, 1311, 755 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.47 (dd, J = 9, 6 Hz, 4 H), 7.4–7.28 (m, 6 H), 5.95 (t, J = 6 Hz, 1 H), 4.19 (d, J = 6 Hz, 2 H), 4.09 (s, 2 H), 2.26 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 145.2, 141.9, 131.9, 129.2, 128.5, 128.2, 126.0, 121.5, 112.5, 87.6, 76.6, 52.2, 44.8, 16.8 ppm. HRMS: calcd. for $C_{19}H_{19}O_2S^+$ $[M + H]^+$ 311.1106; found 311.1114.

General Procedure for the Preparation of Thiopyran 1,1-Dioxides: Sodium hydride (60% in oil; 9 mg, 0.36 mmol, 1.2 equiv.) was added to an ice-cold solution of the respective sulfone (0.3 mmol, 1.0 equiv.) in dry DMSO (10 mL), and the mixture was stirred for the specifed time. After TLC showed that the reaction was complete, it was quenched with water (10 mL), and the mixture was diluted with EtOAc (30 mL). The organic layer was separated, washed with brine (3 × 10 mL), dried (Na_2SO_4), and concentrated under vacuum. The residue was purifed by silica gel column chromatography using petroleum ether/EtOAc as eluent to give the final product.

5-Benzyl-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7A): White solid (67 mg, 75%), m.p. 155 °C (decomposed). IR (neat): $\tilde{\nu}$ = 3059, 2944, 2852, 1618, 1444, 1319, 1120, 753 cm^{-1}. ^{1}H NMR (400 MHz, [D$_3$]acetonitrile): δ = 7.58–7.21 (m, 10 H), 6.62 (s, 1 H), 5.80 (t, J = 4.6 Hz, 1 H), 4.20 (s, 2 H), 3.95 (d, J = 4.6 Hz, 2 H) ppm. ^{13}C NMR (100 MHz, [D$_3$]acetonitrile): δ = 141.9, 140.4, 135.9, 135.6, 130.8, 129.4, 129.1, 128.9, 128.7, 128.3, 128.2, 120.5, 52.1, 52.0 ppm. HRMS: calcd. for $C_{18}H_{17}O_2S^+$ $[M + H]^+$ 297.0944; found 297.0950.

5-(4-Methylbenzyl)-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7B): White solid (80 mg, 85%), m.p. 166–167 °C. IR (neat): $\tilde{\nu}$ = 3036, 2914, 1615, 1441, 1319, 1109, 839, 757 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.41–7.34 (m, 5 H), 7.18–7.10 (m, 4 H), 6.67 (s, 1 H), 5.72 (t, J = 4.6 Hz, 1 H), 4.22 (s, 2 H), 3.95 (d, J = 4.6 Hz, 2 H), 2.35 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 143.0, 140.0, 138.4, 137.8, 132.4, 129.6, 129.5, 129.1, 128.9, 128.6, 128.4, 118.6, 52.4, 52.4, 21.5 ppm. HRMS: calcd. for $C_{19}H_{19}O_2S^+$ $[M + H]^+$ 311.1100; found 311.1095.

5-(4-Methoxybenzyl)-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7C): White solid (88 mg, 90%), m.p. 173–174 °C. IR (neat): $\tilde{\nu}$ = 2961, 2845, 1612, 1447, 1306, 1132, 1026, 845, 750 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.41–7.33 (m, 5 H), 7.33–7.15 (m, 2 H), 6.90–6.87 (m, 2 H), 6.64 (s, 1 H), 5.70 (dd, J = 5.2, 3.9 Hz, 1 H), 4.22 (s, 2 H), 3.95 (d, J = 4.6 Hz, 2 H), 3.81 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 159.7, 143.0, 140.1, 137.4, 130.6, 129.4, 128.6, 128.3, 128.2, 127.7, 118.3, 114.3, 105.0, 100.2, 55.5, 52.4, 52.4 ppm. HRMS: calcd. for $C_{19}H_{19}O_3S^+$ $[M + H]^+$ 327.1049; found 327.1058.

5-(3,4-Dimethylbenzyl)-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7D): White solid (85 mg, 88%), m.p. 142–143 °C. IR (neat): $\tilde{\nu}$ = 3035, 2912 1620, 1445, 1320, 1121, 845, 751 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.40–7.34 (m, 5 H), 7.12 (d, J = 8.2 Hz, 1 H), 6.96 (d, J = 6.8 Hz, 2 H), 6.65 (s, 1 H), 5.71 (t, J = 4.6 Hz, 1 H), 4.24 (s, 2 H), 3.95 (d, J = 4.5 Hz, 2 H), 2.26 (s, 3 H), 2.25 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 143.0, 140.1, 137.9, 137.1, 137.1, 132.8, 130.3, 130.1, 129.4, 128.7, 128.6, 128.3, 126.6, 118.5, 52.5, 52.3, 29.9, 19.9, 19.8 ppm. HRMS: calcd. for $C_{20}H_{21}O_2S^+$ $[M + H]^+$ 325.1257; found 325.1281.

5-(2,4-Dimethoxybenzyl)-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7E): White solid (101 mg, 95%), m.p. 133–134 °C. IR (neat): $\tilde{\nu}$ = 3031, 2965, 2859, 1627, 1449, 1323, 1156, 1035, 750 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.38 (s, 5 H), 7.15 (d, J = 8.4 Hz, 1 H), 6.67 (s, 1 H), 6.49 (d, J = 8.4 Hz, 1 H), 6.42 (s, 1 H), 5.68 (t, J = 4.5 Hz, 1 H), 4.12 (s, 2 H), 3.94 (d, J = 4.4 Hz, 2 H), 3.81 (s, 3 H), 3.74 (s, 3 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 161.5, 158.7, 143.1, 140.1, 134.2, 131.1, 129.5, 128.5, 128.2, 127.9, 117.7, 117.1, 104.6, 98.8, 55.7, 53.6, 52.8, 52.5, 29.9 ppm. HRMS: calcd. for $C_{20}H_{21}O_4S^+$ $[M + H]^+$ 357.1155; found 357.1165.

5-(4-Chlorobenzyl)-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7F): White solid (60 mg, 60%), m.p. 144–145 °C. IR (neat): $\tilde{\nu}$ = 2967, 2851, 1620, 1443, 1312, 1119, 800, 754 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.42–7.04 (m, 9 H), 6.64 (s, 1 H), 5.77 (t, J = 5.6 Hz, 1 H), 4.15 (s, 2 H), 3.95 (d, J = 4.0 Hz, 2 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 142.5, 139.5, 136.2, 133.5, 130.3, 129.2, 128.9, 128.5, 128.3, 119.1, 52.3, 52.1 ppm. HRMS: calcd. for $C_{18}H_{16}ClO_2S^+$ $[M + H]^+$ 331.0554; found 331.0538.

5-Methyl-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7G) and 3-Methyl-4-phenyl-2*H*-thiopyran 1,1-Dioxide (7G′): White gummy mass (50 mg, 75%). IR (neat): $\tilde{\nu}$ = 3268, 2915, 1613, 1416, 1308, 1124, 759 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.39 (ddt, J = 21.3, 14.8, 7.6 Hz, 6 H), 7.30–7.16 (m, 4 H), 6.74 (d, J = 10.8 Hz, 1 H), 6.63–6.48 (m, 2 H), 6.16 (t, J = 5.0 Hz, 1 H), 1.96 (s, 3 H), 1.88 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 146.8, 140.6, 138.9, 138.5, 138.3, 132.7, 131.4, 128.9, 128.7, 128.7, 128.5, 128.2, 126.4, 125.9, 122.9, 55.8, 50.6, 23.0, 22.6 ppm. HRMS: calcd. for $C_{12}H_{13}O_2S^+$ $[M + H]^+$ 221.0631; found 221.0626.

5-Benyl-4-(4-bromophenyl)-2*H*-thiopyran 1,1-Dioxide (7H): White solid (73 mg, 65%), m.p. 195–196 °C. IR (neat): $\tilde{\nu}$ = 3065, 2943, 1655, 1448, 1305, 752, 556 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.56 (d, J = 12 Hz, 2 H), 7.39 (t, J = 6 Hz, 2 H), 7.33 (t, J = 6 Hz, 1 H), 7.25 (d, J = 6 Hz, 2 H), 7.23 (d, J = 12 Hz, 2 H), 6.7 (s, J = 1 Hz), 5.76 (t, J = 6 Hz, 1 H), 4.22 (s, 2 H), 3.97 (d, J = 6 Hz, 2 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 141.7, 138.6, 137.7, 134.9, 131.7, 130.9, 129.1, 128.9, 128.7, 128.3, 122.4, 119.2, 52.1, 30.9 ppm. HRMS: calcd. for $C_{18}H_{15}BrNaO_2S^+$ $[M + Na]^+$ 396.9874; found 396.9875.

4-(4-Bromophenyl)-5-(4-methoxybenzyl)-2*H*-thiopyran 1,1-Dioxide (7I): Off-white solid (84 mg, 70%), m.p. 178–179 °C. IR (neat): $\tilde{\nu}$ = 3037, 2961, 2855, 1635, 1445, 1367, 1132, 1050, 855, 751, 560 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.55 (d, J = 7.8 Hz, 2 H), 7.24 (d, J = 8.4 Hz, 2 H), 7.18 (d, J = 8.4 Hz, 2 H), 6.92 (d, J = 8.4 Hz, 2 H), 6.61 (s, 1 H), 5.71 (t, J = 4.2 Hz, 1 H), 4.23 (s, 2 H), 3.96 (d, J = 3.6 Hz, 2 H), 3.84 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 159.6, 141.9, 138.7, 137.4, 131.6, 130.9, 130.4, 127.6, 127.2, 122.3, 118.5, 114.2, 55.3, 52.2, 52.1 ppm.

HRMS: calcd. for $C_{19}H_{17}BrO_3SNa^+$ [M + Na]$^+$ 426.9974; found 426.9976.

4-(4-Bromophenyl)-5-(4-methylbenzyl)-2*H*-thiopyran 1,1-Dioxide (7J): Pale brown solid (87 mg, 75%), m.p. 172–173 °C. IR (neat): $\tilde{\nu}$ = 3026, 2914, 1632, 1439, 1330, 1110, 845, 754, 562 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.56 (d, J = 7.8 Hz, 2 H), 7.25 (d, J = 7.8 Hz, 2 H), 7.19 (d, J = 7.8 Hz, 2 H), 7.12 (d, J = 7.8 Hz, 2 H), 6.65 (s, 1 H), 5.73 (t, J = 4.2 Hz, 1 H), 4.23 (s, 2 H), 3.96 (d, J = 4.2 Hz, 2 H), 2.37 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 141.8, 138.7, 138.4, 137.8, 131.9, 131.7, 130.9, 129.4, 128.9, 128.4, 122.4, 188.8, 52.2, 52.1, 21.3 ppm. HRMS: calcd. for $C_{19}H_{17}BrO_2SNa^+$[M + Na]$^+$ 411.0030; found 411.0034.

5-(4-Methylbenzyl)-4-*p*-tolyl-2*H*-thiopyran 1,1-Dioxide (7K): Sticky white mass (65 mg, 67%). IR (neat): $\tilde{\nu}$ = 3037, 2922 1623, 1455, 1323, 1120, 847, 751 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.26 (d, J = 7.8 Hz, 2 H), 7.22 (d, J = 7.8 Hz, 2 H), 7.18 (d, J = 7.8 Hz, 2 H), 7.13 (d, J = 8.4 Hz, 2 H), 6.72 (s, 1 H), 5.72 (t, J = 4.2 Hz, 1 H), 4.23 (s, 2 H), 3.96 (d, J = 4.2 Hz, 2 H), 2.41 (s, 3 H), 2.37 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 142.7, 138.1, 138.0, 137.5, 136.9, 132.3, 129.3, 129.1, 128.9, 128.7, 117.9, 52.2, 21.3, 21.2 ppm. HRMS: calcd. for $C_{20}H_{20}O_2SNa^+$ [M + Na]$^+$ 347.1076; found 347.1076.

5-(4-Methoxybenzyl)-4-*p*-tolyl-2*H*-thiopyran 1,1-Dioxide (7L): Sticky white mass (70 mg, 69%). IR (neat): $\tilde{\nu}$ = 3037, 2921, 1633, 1442, 1332, 1109, 847, 755 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.26 (d, J = 7.8 Hz, 2 H), 7.21 (d, J = 7.8 Hz, 2 H), 7.18 (d, J = 8.4 Hz, 2 H), 6.90 (d, J = 9.0 Hz, 2 H), 6.69 (s, 1 H), 5.70 (t, J = 4.8 Hz, 1 H), 4.23 (s, 2 H), 3.96 (d, J = 4.8 Hz, 2 H), 3.84 (s, 3 H), 2.40 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 159.5, 142.8, 138.0, 137.1, 136.9, 130.4, 129.1, 128.0, 127.6, 117.6, 114.1, 55.3, 52.2, 21.2 ppm. HRMS: calcd. for $C_{20}H_{20}O_3SNa^+$ [M + Na]$^+$ 363.1031; found 363.1031.

5-Benzyl-4-*p*-tolyl-2*H*-thiopyran 1,1-Dioxide (7M): Off-white solid (70 mg, 76%) m.p. 147–148 °C. IR (neat): $\tilde{\nu}$ = 3032, 2912, 1614, 1442, 1320, 1110, 840, 750 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.38 (d, J = 7.8 Hz, 2 H), 7.32–7.22 (m, 7 H), 6.75 (s, 1 H), 5.74 (t, J = 4.2 Hz, 1 H), 4.22 (s, 2 H), 3.97 (d, J = 4.2 Hz, 2 H), 2.40 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 142.6, 138.1, 137.5, 136.8, 135.2, 129.4, 129.1, 128.9, 128.6, 128.1, 118.3, 52.3, 52.1, 21.3 ppm. HRMS: calcd. for $C_{19}H_{18}O_2SNa^+$ [M + Na]$^+$ 333.0925; found 333.0925.

9-Phenyl-2-(p-tolylsulfonyl)-2,3,3a,4-tetrahydro-1*H*-benzo[*f*]isoindole (7N): White solid (66 mg, 55%), m.p. 200 °C (decomposed). IR (neat): $\tilde{\nu}$ = 3062, 2928, 2836, 1602, 1441, 1342, 1158, 757 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.72–7.18 (m, 5 H), 7.16 (dd, J = 12.7, 7.1 Hz, 4 H), 7.09 (t, J = 7.2 Hz, 1 H), 6.77 (d, J = 7.6 Hz, 1 H), 4.32 (d, J = 17.3 Hz, 1 H), 4.01 (t, J = 8.8 Hz, 1 H), 3.66 (dd, J = 15.7, 2.5 Hz, 1 H), 3.15 (dd, J = 15.3, 7.0 Hz, 1 H), 2.92 (d, J = 9.1 Hz, 1 H), 2.65 (t, J = 15.1 Hz, 1 H), 2.45 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 143.9, 137.9, 136.9, 135.9, 134.3, 133.4, 132.4, 129.9, 128.8, 127.9, 127.8, 127.3, 126.9, 125.9, 54.5, 50.8, 39.2, 32.9, 21.8 ppm. HRMS: calcd. for $C_{25}H_{24}NO_2S^+$ [M + H]$^+$ 402.1522; found 402.1519.

5-(4-Methylbenzyl)-4-phenyl-3,4-dihydro-2*H*-thiopyran 1,1-Dioxide (12) and 3-(4-Methylbenzyl)-4-phenyl-tetrahydro-thiopyran 1,1-Dioxide (*cis* and *trans*) (13): A solution of thiopyran 1,1-dioxide **7B** (20 mg, 0.06 mmol) in dry methanol (5 mL) was hydrogenated with Pd/C (10%; 8 mg) for 1 h at room temperature. Filtration followed by evaporation gave a crude mixture, from which partially hydrogenated sulfone **12** was isolated in pure form by fractional crystallization from dichloromethane/petroleum ether. The mother liquor comprised an inseparable mixture of *cis* and *trans* tetrahydropyran derivatives **13**.

Data for **12**: White solid (5 mg, 30%), m.p. 145–146 °C. IR (neat): $\tilde{\nu}$ = 3039, 2934 1634, 1447, 1334, 1120, 752 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.43 (t, J = 6 Hz, 2 H), 7.35 (d, J = 12 Hz, 1 H), 7.32 (d, J = 12 Hz, 2 H), 7.22 (d, J = 6 Hz, 2 H), 7.17 (d, J = 6 Hz, 2 H), 6.41 (s, 1 H), 4.08 (d, J = 12 Hz, 1 H), 3.88 (d, J = 18 Hz, 1 H), 3.70 (d, J = 18 Hz, 1 H), 3.34–3.23 (m, 2 H), 2.79–2.73 (m, 1 H), 2.53–2.58 (m, 1 H), 2.36 (s, 3 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 138.9, 137.5, 133.4, 132.4, 131.9, 129.2, 129.0, 128.8, 128.0, 127.4, 54.3, 53.4, 51.1, 48.1, 28.2, 21.2 ppm. HRMS: calcd. for $C_{19}H_{20}O_2SNa^+$ [M + Na]$^+$ 335.1082; found 335.1089.

Data for **13** (*cis* and *trans*): Gummy mass (5 mg, 30%). IR (neat): $\tilde{\nu}$ = 3056, 2945 1665, 1458, 1320, 745 cm^{-1}. ^{1}H NMR (400 MHz, [D]chloroform): δ = 7.43–7.41 (m, 3 H), 7.34–7.24 (m, 6 H), 7.12–7.05 (m, 3 H), 6.94 (d, J = 8 Hz, 2 H), 6.84 (d, J = 8 Hz, 1 H), 3.30–3.01 (m, 9 H), 2.79–2.58 (m, 4 H), 2.53–2.48 (m, 1 H), 2.44–2.28 (m, 8 H), 2.24–2.17 (m, 1 H), 2.10–2.01 (m, 2 H) ppm. ^{13}C NMR (100 MHz, [D]chloroform): δ = 141.8, 136.3, 136.0, 129.6, 129.4, 129.1, 129.0, 127.8, 127.3, 55.3, 53.6, 52.3, 51.9, 48.7, 44.6, 43.9, 29.9, 25.0, 22.9, 21.2, 14.3 (some peaks may have overlapped) ppm. HRMS: calcd. for $C_{19}H_{23}O_2S^+$ [M + H]$^+$ 315.1413; found 315.1407.

3-Methylene-4-phenyl-3,6-dihydro-2*H*-thiopyran 1,1-Dioxide (25): Pale yellow solid (176 mg, 80%), m.p. 135–136 °C. IR (neat): $\tilde{\nu}$ = 3210, 2945, 1615, 1420, 1310, 1125, 760 cm^{-1}. ^{1}H NMR (600 MHz, [D]chloroform): δ = 7.39–7.37 (m, 3 H), 7.30–7.28 (m, 2 H), 5.74 (t, J = 4.2 Hz, 1 H), 5.40 (s, 1 H), 5.20 (s, 1 H), 3.98 (s, 2 H), 3.94 (d, J = 4.2 Hz, 2 H) ppm. ^{13}C NMR (150 MHz, [D]chloroform): δ = 141.4, 139.2, 135.9, 128.9, 128.3, 128.2, 123.3, 119.2, 57.0, 52.2 ppm. HRMS: calcd. for $C_{12}H_{12}O_2SNa^+$ [M + Na]$^+$ 243.0450; found 243.0452.

Acknowledgments

A. B. is grateful to the Council of Scientific and Industrial Research (CSIR), New Delhi, for funding, and to the Department of Science and Technology (DST), New Delhi, for a J. C. Bose fellowship. I. H. and J. D. thank the CSIR for a research fellowship (NET). The DST is also thanked for the funds for a 400 MHz NMR facility under the IRPHA program.

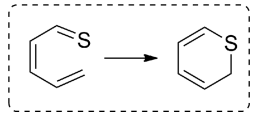
[1] T. Mitra, J. Das, M. Maji, R. Das, U. K. Das, P. K. Chattaraj, A. Basak, *RSC Adv.* **2013**, *3*, 19844.

[2] a) S. Braverman, D. Segev, *J. Am. Chem. Soc.* **1974**, *96*, 1245; b) P. J. Garratt, S. B. Neoh, *J. Am. Chem. Soc.* **1975**, *97*, 3255; c) S. Braverman, Y. Duar, D. Segev, *Tetrahedron Lett.* **1976**, *17*, 3181; d) P. J. Garratt, S. Neoh, *J. Org. Chem.* **1979**, *44*, 2667; e) Y. S. P. Cheng, P. J. Garratt, S. B. Neoh, V. H. Rumjanek, *Isr. J. Chem.* **1985**, *26*, 101; f) S. Braverman, Y. Duar, *J. Am. Chem. Soc.* **1990**, *112*, 5830; g) Y. Zafrani, H. E. Gottlieb, M. Sprecher, S. Braverman, *J. Org. Chem.* **2005**, *70*, 10166.

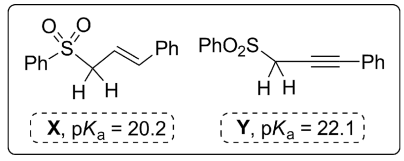
[3] a) Y. Zafrani, H. E. Gottlieb, M. Sprecher, S. Braverman, *J. Org. Chem.* **2005**, *70*, 10166; b) S. Mondal, T. Mitra, R. Mukherjee, P. S. Addy, A. Basak, *Synlett* **2012**, *23*, 2582; c) S. Mondal, A. Basak, S. Jana, A. Anoop, *Tetrahedron* **2012**, *68*, 7202; d) P. S. Addy, S. Dutta, K. Biradha, A. Basak, *Tetrahedron Lett.* **2012**, *53*, 19; e) S. Mondal, M. Maji, A. Basak, *Tetrahedron Lett.* **2010**, *52*, 1183; f) R. K. Mohamed, P. W. Peterson, I. V. Alabugin, *Chem. Rev.* **2013**, *113*, 7089.

[4] M. Maji, D. Mallick, S. Mandal, A. Anoop, S. S. Bag, A. Basak, E. D. Jemmis, *Org. Lett.* **2011**, *13*, 888.

[5] T. Kudoh, T. Mori, M. Shirahama, T. Yamada, S. Ishikawa, H. Saito, H. Kobayashi, *J. Am. Chem. Soc.* **2007**, *129*, 4939.
[6] a) A. Basak, S. Das, D. Mallick, E. D. Jemmis, *J. Am. Chem. Soc.* **2009**, *131*, 15695; b) R. Mukherjee, S. Mondal, A. Basak, D. Mallick, E. D. Jemmis, *Chem. Asian J.* **2012**, *7*, 957.
[7] a) F. Xue, C. T. Seto, *J. Org. Chem.* **2005**, *70*, 8309; b) M. Baumgarth, N. Beier, R. Gericke, *J. Med. Chem.* **1998**, *41*, 3736.
[8] J. D. Hepworth, B. M. Heron, *Thiopyrans and their Benzo Derivatives*, in: *Comprehensive Heterocyclic Chemistry III* (Eds.: A. R. Katritzky, C. A. Ramsden, E. F. V. Scriven, R. J. K. Taylor), **2008**, vol. 7, p. 727–954.
[9] a) F. M. Koch, R. Peters, *Chem. Eur. J.* **2011**, *17*, 3679; b) M. Zajac, R. Peters, *Chem. Eur. J.* **2009**, *15*, 8204.
[10] a) X. Cao, Y. Yang, X. Wang, *J. Chem. Soc. Perkin Trans. 1* **2002**, *22*, 2485; b) K. Kato, M. Ono, H. Akita, *Tetrahedron* **2001**, *57*, 10055.
[11] a) T. Aoyama, T. Takido, M. Kodomari, *Synth. Commun.* **2003**, *33*, 3817; b) X.-P. Cao, *Tetrahedron* **2002**, *58*, 1301.
[12] a) J. Das, R. Mukherjee, A. Basak, *J. Org. Chem.* **2014**, *79*, 3789; b) Y. Miyake, S. Ota, Y. Nishibayashi, *Chem. Eur. J.* **2012**, *18*, 13255.
[13] The ^{1}H NMR spectrum of the chloro-substituted thiopyran 1,1-dioxide derivatives showed the desired product with some impurity (inseparable by HPLC).
[14] S. Rossi, G. Pagani, *Tetrahedron Lett.* **1966**, 2129.
[15] a) P. J-M. B. Raboisson, K. Vandyck, O. Nyanguile, D. C. McGowan, S. M. H. Vendeville, K. I. E. Amssoms, C. W. M. Boutton, P. M. J. Lory, L. Hu, W. M. M. Van den Broeck, WO 2008099020 A1, **2008**; b) T. J. Poel, J. M. Patrick, M. Robert, US 6083967, **2000**.
[16] a) Exothermicity has been assumed in view of the fact that in this 6π-electrocyclization one C–C π bond is replaced by a C–C σ bond, along with the formation of a stable six-membered ring. Moreover, the reaction occurs at a low temperature (0 °C). DFT-based calculations on an oxa-6π-electrocyclization predicted exothermicity, see: M. A. Kienzler, Ph. D. dissertation, **2010**, p. 4 http://escholarship.org/uc/item/6158904v; b) a computational description of 6π-electrocyclization involving a C=S bond has been reported; this predicted equilibration in favour of the cyclic thiopyran derivative, see: B. Y. Simkin, S. P. Makarov, V. I. Minkin, *Chem. Heterocycl. Compd. (N. Y., NY, U. S.)* **1982**, *18*, 779; c) an alternative mechanism that could have been considered involves a 6-*exo*-*dig* process (favourable according to Baldwin's rules: J. E. Baldwin, *J. Chem. Soc., Chem. Commun.* **1976**, 734–736). We have not considered this possibility in view of the failure to isolate a pyran or piperidine ring system from the ethers or sulfonamide, respectively;



d) the introduction of a sulfone moiety bridging the propargylic and allylic arms changed the reactivity compared to what was reported for the corresponding ether (and also observed for the sulfonamide). One may argue that this difference in reactivity is due to the lower pK_a difference (ΔpK_a) for the propargylic and allylic hydrogens as compared to the corresponding ether system. Although there is a literature report of ΔpK_a between cinnamyl sulfone (X) and phenyl propargyl sulfone (Y); see: F. G. Bordwell, *Acc. Chem. Res.* **1988**, *21*, 456–463, we could not find the corresponding value for an ether/sulfonamide system. However, considering the pK_a of H_2/H^- to be 35, deprotonation may be expected to occur at both the propargylic and allylic positions for both the systems.



[17] a) E. J. Corey, H. Koenig, T. H. Lowry, *Tetrahedron Lett.* **1962**, *3*, 515; b) R. Kumar, D. Nair, I. Namboothiri, *Tetrahedron* **2014**, *70*, 1794; c) R. E. Deasy, N. O. Riordan, A. R. Maguire, *Catalyst* **2014**, *4*, 186; d) D. S. Argyropoulos, H. Sadeghifar, C. Cui, S. Sen, *ACS Sustainable Chem. and Eng.* DOI: rg/10.1021/sc4002998.

Received: May 15, 2015
Published Online: August 14, 2015

