

Picosecond radical kinetics. Rate constants for ring openings of 2-aryl-substituted cyclopropylcarbinyl radicals

Martin Newcomb, Seung-Yong Choi, and Patrick H. Toy

Abstract: The kinetics of ring openings of a series of eight (*trans*-2-arylcyclopropyl)methyl radicals (**1**) were studied by indirect kinetic methods using Barton's PTOC esters as radical precursors and reaction with PhSeH as the competition reaction. The substituents were CF₃, F, Me, and OMe located on both the *para* and *meta* positions of the aromatic ring. Syntheses of the radical precursors and the products of the radical reactions are described. Kinetics were determined between -43 and 25°C in four cases (CF₃ and OMe substituents) and at 0 and 25°C in the other four cases. The rate constants at 25°C ranged from $1.0 \times 10^{11} \text{ s}^{-1}$ (*p*-CH₃) to $4.1 \times 10^{11} \text{ s}^{-1}$ (*p*-CF₃). The relatively large acceleration of the *p*-CF₃ group, ca. 2.5 times as fast as the parent system with Ar = Ph, correlates well with Adam's ΔD substituent parameters but not with other radical substituent parameters. These calibrated radical rearrangements provide a new set of ultrafast reactions that can be applied in mechanistic probe studies.

Key words: cyclopropylcarbinyl radical, kinetics, PTOC esters, benzeneselenol.

Résumé : On a étudié la cinétique de l'ouverture de cycle d'une série de huit radicaux (*trans*-2-arylcyclopropyl)méthyles (**1**) à l'aide de méthodes cinétiques indirectes, en utilisant les esters PTOC de Barton comme précurseurs des radicaux et la réaction avec le PhSeH comme réaction en compétition. Des substituants CF₃, F, Me et OMe ont été placés dans les positions *ortho* ainsi que *mé*ta du noyau aromatique. On décrit les synthèses des précurseurs de radicaux ainsi que celles des produits des réactions radicalaires. Dans quatre cas (substituants CF₃ et OMe), on a déterminé les cinétiques à des températures entre -43 à +25°C et à 0 et 25°C dans les quatre autres cas. Les constantes de vitesse à 25°C vont de $1,0 \times 10^{11} \text{ s}^{-1}$ (*p*-CH₃) à $4,1 \times 10^{11} \text{ s}^{-1}$ (*p*-CF₃). L'accélération relativement importante observée avec le groupe *p*-CF₃, environ 2,5 fois plus rapide que le système parent dans lequel Ar = Ph, donne une bonne corrélation avec les paramètres de substituants ΔD de Adam, mais ce n'est pas le cas avec les autres paramètres de substituants radicalaires. Ces réarrangements radicalaires calibrés fournissent un nouvel ensemble de réactions ultrarapides qui peuvent être appliquées comme sonde dans des études mécanistiques.

Mots clés : radical cyclopropylcarbinyle, cinétique, esters PTOC, benzènesélenol.

[Traduit par la Rédaction]

Rearrangements of radicals have been employed qualitatively in mechanistic probes to implicate radical intermediates and quantitatively as clocks to time radical reactions (1, 2). 2-Aryl-substituted cyclopropylcarbinyl radicals fragment quite rapidly with transient lifetimes in the picosecond range at ambient temperature (3–5), and (*trans*-2-phenylcyclopropyl)methane and related species have been applied in studies of the mechanisms of enzyme-catalyzed hydroxylation reactions (6–14). The phenyl group provides acceleration of the radical reaction, but the aromatic ring is subject to oxidation by enzymes, resulting in phenolic by-products. In addition,

because the skeletal reorganization of radical and cationic intermediates is the same, such probes do not permit an inherent distinction between these two types of intermediates. In an effort to provide a wide range of fast radical probes including species that are not oxidized to phenols and that might provide information permitting distinction between radicals and cations, we have calibrated a series of 2-aryl-substituted cyclopropylcarbinyl radical ring openings. The kinetics of the rearrangements are reported here.

Precursors and products

The kinetics of ring openings for the series of radicals **1** were determined by an indirect method using Barton's PTOC esters (**2**) (**15**) as radical precursors and benzeneselenol trapping as the basis reaction (Scheme 1) (**3**, **16**–**18**). The PTOC esters react in radical chain reactions to give acyloxyl radicals (**3**) that decarboxylate rapidly to give radicals **1**. Ring openings of radicals **1** give benzylic radicals **4** in competition with trapping by PhSeH that produces the cyclopropanes **5**. Benzylic radicals **4** also react with PhSeH

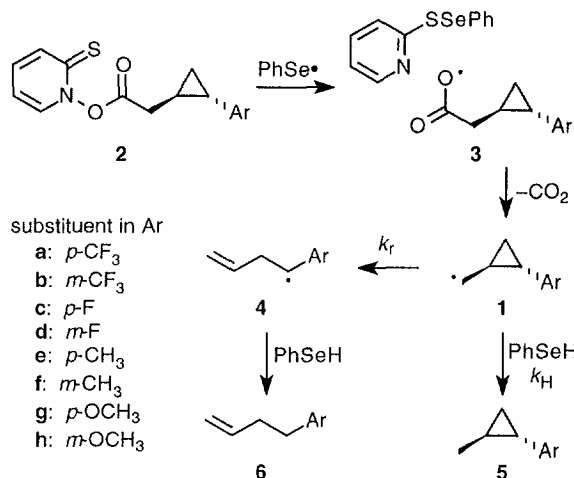
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This paper is dedicated to Jerry Kresge in recognition of his many achievements in chemistry.

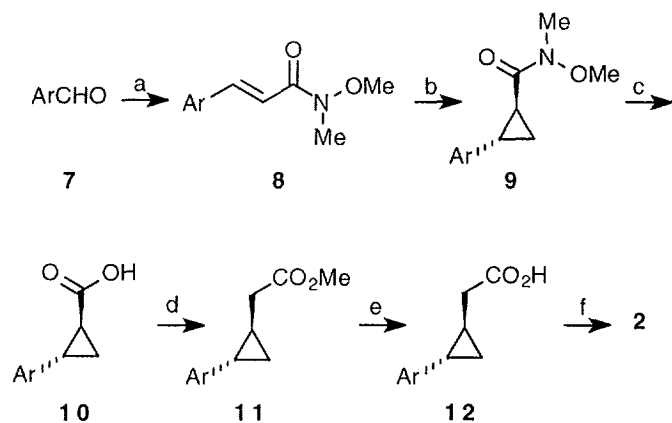
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Scheme 1.



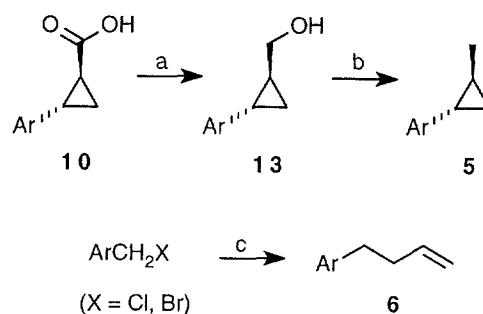
Scheme 2. (a) Ph₃P = CHC(O)NMeOMe, CH₂Cl₂; (b) Me₃SO⁺ I⁻, NaH, DMSO; (c) *t*-BuOK, H₂O, Et₂O; (d) i. (COCl)₂, DMF, C₆H₆, ii. CH₂N₂, Et₂O, iii. Ag₂O, Na₂S₂O₃, H₂O, reflux, iv. CH₂N₂, Et₂O; (e) LiOH, MeOH, H₂O; (f) Bu₃P, 2,2'-dipyridyl disulfide bis-*N*-oxide, CH₂Cl₂.



giving alkenes **6**, and the PhSe* radical formed in these processes propagates the chain reaction.

PTOC esters are prepared from the corresponding carboxylic acids. For economy in synthesis, the sequence of reactions shown in Scheme 2 was employed. This sequence permits the preparation of the requisite carboxylic acids and the cyclic products of the radical reactions from advanced intermediates. The commercially available substituted benzaldehydes **7** were first converted to the corresponding Weinreb amides (**19**) **8** by Wittig olefination with *N*-methoxy-*N*-methyl-2-(triphenylphosphoronylidene)acetamide. The acrylamide derivatives **8** were cyclopropanated in reactions with the ylide from trimethylsulfoxonium iodide and sodium hydride according to the procedure developed by Rodrigues (20) to afford the cyclopropylcarboxamides **9**. Hydrolysis of amides **9** by the anhydrous hydroxide procedure of Gassman et al. (21) gave acids **10**, which were homologated to the corresponding (2-arylcyclopropyl)acetic acids. For purification purposes, the homologated acids were converted to esters **11**, which were isolated and then

Scheme 3. (a) LiAlH₄, THF; (b) i. MsCl, Et₃N, THF, -30°C, ii. LiBEt₃H, THF, -78°C; (c) CH₂ = CHCH₂MgCl, Et₂O, reflux.



saponified to afford acids **12**. The requisite acids were converted to PTOC esters **2** by conventional methods.

Authentic samples of the trapped and rearranged products of the radical reactions were prepared (Scheme 3). The cyclopropanes **5** were prepared in two steps from acids **10**. Lithium aluminum hydride reduction of the acids gave alcohols **13** that were reduced to cyclopropanes **5** by conversion to the mesylate derivatives and reduction with lithium triethylborohydride (22). The acyclic products from radical ring opening (**6**) were prepared by reaction of the appropriate substituted benzylic halide with allylmagnesium chloride (23).

Kinetics

PTOC esters **2** were allowed to react in THF in the presence of PhSeH in indirect kinetic studies similar to those previously reported. Solutions were shielded from light during a thermal equilibration period. The solutions were then irradiated with visible light, which cleaves the PTOC esters and initiates the radical chain reactions. Following the radical chain reactions, the reaction mixtures were analyzed by GC. The yields of products were generally in the range of 60–80%, which is typical for this type of study. The *m*-CF₃-substituted system had yields of 40–50%. The PTOC esters are activated acyl derivatives that can react with PhSeH in polar reactions, and the intermediate acyloxy radicals can be trapped by PhSeH in competition with decarboxylation; both side reactions reduce the overall yield but have no effect on the kinetics.

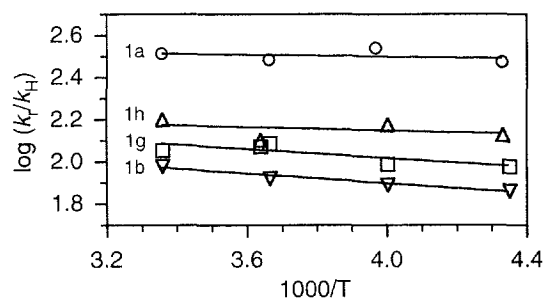
The indirect kinetic results are collected in Table 1. PhSeH is one of the fastest radical trapping agents available, but the ring-opening reactions are so fast that ring-opened products greatly predominated. Table 1 contains the ratios of rate constants for rearrangement and trapping (k_r/k_H) with errors at 1 σ . For radicals **1a**, **1b**, **1g**, and **1h**, relative rate constants were determined between -43 and 25°C, and the relative Arrhenius functions for these radicals are shown graphically in Fig. 1. The log *A* terms in the relative Arrhenius functions are similar for these radicals, as expected for the case of remote substituents, giving a weighted average log *A* term of (2.4 ± 0.1) (error at 2 σ).

The indirect kinetic method provides relative rate constants for rearrangement (k_r) and trapping by PhSeH (k_H). In the original calibration of the ring opening of the parent radical (**1**, Ar = Ph), the rate constants for reaction of PhSeH employed were determined by competition against ring

Table 1. Results of competition kinetic studies with radicals **1**.

Radical (subs)	Temp (°C)	Runs	k_r/k_H^a (M)	Avg % yield
1a (<i>p</i> -CF ₃)	25	4	327 ± 12	78
	0	4	305 ± 9	74
	-21	4	346 ± 40	79
	-42	4	297 ± 38	65
1b (<i>m</i> -CF ₃)	25	3	96 ± 6	52
	0	3	84 ± 3	52
	-23	3	78 ± 5	46
	-43	3	73 ± 5	41
1g (<i>p</i> -OMe)	25	3	114 ± 10	72
	2	3	119 ± 11	84
	0	2	123 ± 14	84
	-23	3	98 ± 5	77
	-43	3	96 ± 2	65
1h (<i>m</i> -OMe)	25	3	160 ± 4	67
	0	3	128 ± 6	58
	-23	3	151 ± 16	63
	-42	4	135 ± 12	69
1e (<i>p</i> -CH ₃)	25	3	83 ± 2	71
	0	3	80 ± 6	76
1f (<i>m</i> -CH ₃)	25	3	207 ± 16	81
	0	3	141 ± 11	79
1c (<i>p</i> -F)	25	3	117 ± 4	86
	0	3	100 ± 2	85
1d (<i>m</i> -F)	25	3	159 ± 9	77
	0	3	159 ± 11	78

^aRelative rate constants for ring opening and reaction with PhSeH; errors are 1σ.

Fig. 1. Relative rate constants for ring openings and PhSeH trapping of radicals **1a**, **1b**, **1g**, and **1h**. The lines are regression fits.

opening of the cyclopropylcarbonyl radical. However, a recent recalibration (18) of alkyl radical trapping by reactive H-atom donors indicated that the original rate constants for PhSeH were too large by about 30% due to an error in rate constants introduced early in the sequence of indirect kinetic studies. Accordingly, we suggested that the rate constants for reaction of PhSeH with cyclopropylcarbonyl radicals are likely to be quite similar to those for reaction of primary alkyl radicals (18).

We assume, therefore, that the rate constants for PhSeH trapping of radicals **1** are equal to those recently determined for reactions of PhSeH with a primary alkyl radical. The rate constants for PhSeH determined at ambient temperature are likely to be the most accurate, as previously discussed (18). In Table 2, we have used the rate constant for reaction of PhSeH with 1° alkyl radicals at 25°C ($1.26 \times 10^9 \text{ M}^{-1} \text{ s}^{-1}$)

Table 2. Rate constants and estimated Arrhenius functions for ring openings of radicals **1**.

Radical (subs)	k_{25} (s ⁻¹) ^a	Arrhenius function ^b
1 (Ar = Ph) ^c	1.6×10^{11}	13.1 - 2.58/θ
1a (<i>p</i> -CF ₃)	4.1×10^{11}	13.1 - 2.02/θ
1b (<i>m</i> -CF ₃)	1.2×10^{11}	13.1 - 2.75/θ
1c (<i>p</i> -F)	1.5×10^{11}	13.1 - 2.66/θ
1d (<i>m</i> -F)	2.0×10^{11}	13.1 - 2.45/θ
1e (<i>p</i> -Me)	1.0×10^{11}	13.1 - 2.86/θ
1f (<i>m</i> -Me)	2.6×10^{11}	13.1 - 2.29/θ
1g (<i>p</i> -OMe)	1.4×10^{11}	13.1 - 2.62/θ
1h (<i>m</i> -OMe)	2.0×10^{11}	13.1 - 2.45/θ

^aRate constant at 25°C.

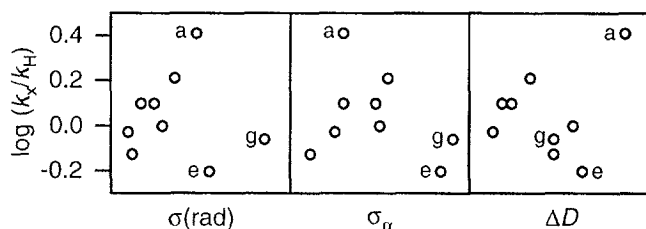
^bEquals $(\log k \times s)$; $\theta = 2.3RT$ in kcal/mol. See text for assumptions.

^cSee ref. 18.

(18) and the relative rate constants for ring openings and trapping of radicals **1** to calculate absolute rate constants for ring openings at 25°C. Radicals **1** are extremely short lived with lifetimes ($\tau = 1/k$) at 25°C of only 2.4–10 ps.

In considering such reactive species, one might question whether or not the methods provide true statistical averaging. This appears to be the case for radicals **1**. In the recent study of PhSeH trapping kinetics, the radical clock used for calibration cyclized with a rate constant of $3.7 \times 10^7 \text{ s}^{-1}$ at 20°C and demonstrated excellent Arrhenius behavior in direct LFP kinetic studies (18). The relative rate constants and Arrhenius function for PhSeH trapping determined in that work should be quite reliable. Using the log A term for

Fig. 2. Correlations of relative rate constants for ring openings of radicals **1** at 25°C with Creary's $\sigma(\text{rad})$ scale (25), Arnold's σ_α scale (26), and Adam's ΔD scale (27). In each plot, the points for radicals **1a**, **1e**, and **1g** are labeled with the corresponding letters.



PhSeH trapping ($\log A = 10.73 \pm 0.14$) (18) and the weighted average relative $\log A$ term for ring opening and trapping of radicals **1** noted above, the calculated $\log A$ term for ring openings of radicals **1** is 13.1 ± 0.2 . This value is in excellent agreement that those typically found for cyclopropylcarbonyl radical ring openings including those determined with high precision in direct LFP kinetic studies of a series of cyclopropylcarbonyl radicals containing UV-detectable reporter groups (24).

On the basis of the consistent Arrhenius entropic term and its agreement with previous results, one expects that good estimates of rate constants for ring openings of radicals **1** at varying temperatures can be calculated by employing the rate constants determined at 25°C, the most reliable values, and an Arrhenius $\log A$ term of 13.1. Table 2 contains temperature-dependent functions for rearrangements of radicals **1** thus calculated.

Remote substituent effects in radical reactions have been considered previously. These effects are generally small, and Hammett-type treatments have large relative errors. The rate constants for ring openings of radicals **1** correlate poorly with the substituent parameters $\sigma(\text{rad})$ of Creary et al. (25), σ_α of Wayner and Arnold (26), and ΔD of Adam et al. (27) (Fig. 2). The fit is especially poor for the *p*-CF₃ (**1a**), *p*-Me (**1e**), and *p*-OMe (**1g**) cases using the $\sigma(\text{rad})$ and σ_α parameters. It is interesting to note, however, that the large substituent value for *p*-CF₃ in the ΔD scale is in good agreement with the relatively large kinetic effect found in this work.

In summary, rate constants for ring openings of a variety of *trans*-2-arylcyclopropylcarbonyl radicals are now available. The ultrafast rearrangements permit quantitation of extremely short "radical" lifetimes including lifetimes in the transition states for insertion reactions. In addition, the corresponding (arylcyclopropyl)methanes containing the *p*-CF₃ and *p*-F substituents were found to be resistant to arene oxidation (i.e., phenol production) in reactions with cytochrome P450 enzymes (13) and methane monooxygenase hydroxylase enzyme (28).

Experimental section

General methods

Commercially available reagents were purchased from the Aldrich Chemical Company and were used as received. All moisture-sensitive reactions were carried out in flame-dried glassware under a nitrogen atmosphere. Tetrahydrofuran

(THF) and diethyl ether were distilled under a nitrogen atmosphere over sodium and benzophenone ketyl. Methylene chloride was distilled under a nitrogen atmosphere over phosphorus pentoxide. Dimethyl sulfoxide (DMSO) was distilled in vacuo from calcium hydride.

¹H and ¹³C NMR spectra of CDCl₃ solutions were obtained at 300 or 500 MHz and 75 or 125 MHz, respectively. Gas chromatographic analyses were performed using flame ionization detection on a Varian 3400 chromatograph (15 m × 0.54 mm bonded phase SE-30 and Carbowax columns, Alltech). High-resolution mass spectral analyses were performed by the Central Instrumentation Facility at Wayne State University (Detroit, Mich.). Melting points were determined using a Unimelt capillary melting point apparatus (Thomas Hoover) and are uncorrected. Radial chromatography was performed on a Chromatotron model 7294T (Harrison Research Corp.) using plates coated with TLC grade silica gel (Merck) with gypsum binder and fluorescent indicator.

trans-1-Methyl-2-(4-(trifluoromethyl)phenyl)cyclopropane (**5a**). Procedure G

A solution of **13a** (0.28 g, 1.31 mmol) in THF (8 mL) under a nitrogen atmosphere was cooled to -30°C. To this was added sequentially via syringe triethylamine (0.45 mL, 3.23 mmol) and methanesulfonyl chloride (0.11 mL, 1.42 mmol). The mixture was stirred at -30°C for 30 min and then cooled to -78°C. A solution of LiBEt₃H (1.0 M in THF, 4.0 mL, 4.0 mmol) was added via syringe. The mixture was allowed to warm slowly to room temperature and was stirred for 13 h. The reaction mixture was quenched by the addition of 30% H₂O₂ (2 mL) and 15% aqueous NaOH (2 mL). The resulting mixture was heated at reflux for 1 h and then cooled to room temperature. The organic layer was separated, and the aqueous layer was extracted with ether (3 × 25 mL). The combined organic phase was washed with brine (50 mL), dried over MgSO₄, filtered, and concentrated in vacuo at 0°C. The crude product was purified by radial chromatography (pentane) to afford **5a** (0.21 g, 1.04 mmol, 79%) as a clear, colorless oil. ¹H NMR (CDCl₃) δ : 0.80–0.86 (1H, m), 0.94 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 4.8$ Hz), 1.06–1.16 (1H, m), 1.20 (3H, d, $J = 5.7$ Hz), 1.62 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 4.5$ Hz), 7.10 (2H, d, $J = 8.4$ Hz), 7.48 (2H, d, $J = 8.4$ Hz). ¹³C NMR (CDCl₃) δ : 18.3, 18.9, 18.9, 24.2, 124.6 (q, $J_{\text{C-F}} = 270.2$ Hz), 125.1 (2C, q, $J_{\text{C-F}} = 2.9$ Hz), 125.6 (2C), 127.4 (q, $J_{\text{C-F}} = 31.6$ Hz), 148.6. HRMS calcd. for C₁₁H₁₁F₃; 200.0813; found: 200.0808.

trans-1-Methyl-2-(3-(trifluoromethyl)phenyl)cyclopropane (**5b**) was prepared by procedure G, from **13b** (0.33 g, 1.53 mmol), triethylamine (0.45 mL, 3.23 mmol), methanesulfonyl chloride (0.14 mL, 1.83 mmol), and LiBEt₃H (8.0 mL, 8.0 mmol), in 59% yield (0.18 g, 0.90 mmol). ¹H NMR (CDCl₃) δ : 0.83 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz), 0.94 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 4.8$ Hz), 1.05–1.17 (1H, m), 1.22 (3H, d, $J = 5.7$ Hz), 1.65 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 4.5$ Hz), 7.19–7.41 (4H, m). ¹³C NMR (CDCl₃) δ : 17.8, 18.4, 18.9, 24.1, 121.9 (q, $J_{\text{C-F}} = 3.3$ Hz), 122.2 (q, $J_{\text{C-F}} = 3.3$ Hz), 124.3 (q, $J_{\text{C-F}} = 270.2$ Hz), 128.5, 128.8, 130.5 (q, $J_{\text{C-F}} = 32.0$ Hz), 145.1. HRMS calcd. for C₁₁H₁₁F₃; 200.0813; found: 200.0816.

trans-1-Methyl-2-(4-fluorophenyl)cyclopropane (5c) was prepared by procedure G, from **13c** (0.83 g, 4.99 mmol), triethylamine (1.40 mL, 10.0 mmol), methanesulfonyl chloride (0.45 mL, 5.81 mmol), and LiBEt₃H (20.0 mL, 20.0 mmol), in 53% yield (0.40 g, 2.66 mmol). ¹H NMR (CDCl₃) δ: 0.74 (1H, ddd, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz, *J*₃ = 4.8 Hz), 0.85 (1H, dt, *J*₁ = 8.1 Hz, *J*₂ = 5.4 Hz), 0.96–1.08 (1H, m), 1.21 (3H, d, *J* = 5.7 Hz), 1.58 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 4.8 Hz), 6.91–7.04 (4H, m). ¹³C NMR (CDCl₃) δ: 17.3, 17.7, 19.0, 23.6, 114.9 (2C, d, *J*_{C-F} = 20.9 Hz), 126.8 (2C, d, *J*_{C-F} = 7.5 Hz), 139.5, 160.9 (d, *J*_{C-F} = 241.6 Hz). HRMS calcd. for C₁₀H₁₁F: 150.0845; found: 150.0842.

trans-1-Methyl-2-(3-fluorophenyl)cyclopropane (5d) was prepared by procedure G, from **13d** (0.80 g, 4.81 mmol), triethylamine (1.40 mL, 10.0 mmol), methanesulfonyl chloride (0.45 mL, 5.81 mmol), and LiBEt₃H (20.0 mL, 20.0 mmol), in 73% yield (0.53 g, 3.53 mmol). ¹H NMR (CDCl₃) δ: 0.81 (1H, ddd, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz, *J*₃ = 4.5 Hz), 0.93 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 4.8 Hz), 1.04–1.16 (1H, m), 1.23 (3H, d, *J* = 6.0 Hz), 1.61 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 4.8 Hz), 6.72–6.89 (3H, m), 7.18–7.24 (1H, m). ¹³C NMR (CDCl₃) δ: 17.9, 18.3, 18.9, 24.2, 111.9 (d, *J*_{C-F} = 7.1 Hz), 112.1 (d, *J*_{C-F} = 17.7 Hz), 121.3 (d, *J*_{C-F} = 2.3 Hz), 129.5 (d, *J*_{C-F} = 8.9 Hz), 147.0 (d, *J*_{C-F} = 6.7 Hz), 163.1 (d, *J*_{C-F} = 242.7 Hz). HRMS calcd. for C₁₀H₁₁F: 150.0845; found: 150.0851.

trans-1-Methyl-2-(4-methylphenyl)cyclopropane (5e) was prepared by procedure G, from **13e** (0.86 g, 5.30 mmol), triethylamine (1.50 mL, 10.8 mmol), methanesulfonyl chloride (0.45 mL, 5.81 mmol), and LiBEt₃H (25.0 mL, 25.0 mmol), in 45% yield (0.35 g, 2.39 mmol). ¹H NMR (CDCl₃) δ: 0.71–0.77 (1H, m), 0.85–0.91 (1H, m), 0.99–1.11 (1H, m), 1.21 (3H, d, *J* = 5.7 Hz), 1.64 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 4.5 Hz), 2.42 (3H, s), 6.92–7.26 (4H, m). ¹³C NMR (CDCl₃) δ: 17.3, 17.6, 19.1, 20.9, 24.0, 125.4 (2C), 128.9 (2C), 134.6, 140.9. HRMS calcd. for C₁₁H₁₄: 146.1096; found: 146.1099.

trans-1-Methyl-2-(3-methylphenyl)cyclopropane (5f) was prepared by procedure G, from **13f** (0.76 g, 4.68 mmol), triethylamine (1.40 mL, 10.0 mmol), methanesulfonyl chloride (0.45 mL, 5.81 mmol), and LiBEt₃H (20.0 mL, 20.0 mmol), in 76% yield (0.52 g, 3.56 mmol). ¹H NMR (CDCl₃) δ: 0.82 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 4.5 Hz), 0.98 (1H, dt, *J*₁ = 8.1 Hz, *J*₂ = 4.8 Hz), 1.09–1.21 (1H, m), 1.22 (3H, d, *J* = 5.7 Hz), 1.58 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 4.8 Hz), 2.34 (3H, s), 6.98 (2H, d, *J* = 8.1 Hz), 7.09 (2H, d, *J* = 8.1 Hz). ¹³C NMR (CDCl₃) δ: 17.5, 17.9, 19.1, 21.5, 24.3, 122.5, 126.0, 126.4, 128.2, 137.8, 144.0. HRMS calcd. for C₁₁H₁₄: 146.1096; found: 146.1095.

trans-1-Methyl-2-(4-methoxyphenyl)cyclopropane (5g) was prepared by procedure G, from **13g** (0.49 g, 2.75 mmol), triethylamine (0.80 mL, 5.74 mmol), methanesulfonyl chloride (0.25 mL, 3.23 mmol), and LiBEt₃H (11.0 mL, 11.0 mmol), in 65% yield (0.29 g, 1.79 mmol). ¹H NMR (CDCl₃) δ: 0.67 (1H, dt, *J*₁ = 8.1 Hz, *J*₂ = 4.8 Hz), 0.80 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 4.8 Hz), 0.91–1.03 (1H, m), 1.17 (3H, d, *J* = 6.3 Hz), 1.53 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 4.5 Hz), 3.78 (3H, s), 6.80 (2H, dt, *J*₁ = 8.4 Hz, *J*₂ = 3.3 Hz), 6.97 (2H, dt,

*J*₁ = 9.0 Hz, *J*₂ = 2.7 Hz). ¹³C NMR (CDCl₃) δ: 17.0, 17.3, 19.1, 23.6, 55.3, 113.8 (2C), 126.6 (2C), 136.0, 157.5. HRMS calcd. for C₁₁H₁₄O: 162.1045; found: 162.1046.

trans-1-Methyl-2-(3-methoxyphenyl)cyclopropane (5h) was prepared by procedure G, from **13h** (0.38 g, 2.13 mmol), triethylamine (0.60 mL, 4.30 mmol), methanesulfonyl chloride (0.20 mL, 2.58 mmol), and LiBEt₃H (9.0 mL, 9.0 mmol), in 55% yield (0.19 g, 1.17 mmol). ¹H NMR (CDCl₃) δ: 0.86 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 4.8 Hz), 1.02 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.1 Hz), 1.13–1.25 (1H, m), 1.31 (3H, d, *J* = 5.7 Hz), 1.68 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.1 Hz), 3.88 (3H, s), 6.73–6.82 (3H, m), 7.28 (1H, t, *J* = 7.8 Hz). ¹³C NMR (CDCl₃) δ: 17.8, 18.1, 19.2, 24.5, 55.1, 110.5, 111.5, 118.0, 129.3, 145.9, 159.8. HRMS calcd. for C₁₁H₁₄O: 162.1045; found: 162.1047.

4-(4-(Trifluoromethyl)phenyl)but-1-ene (6a). Procedure H

A solution of 4-(trifluoromethyl)benzyl chloride (0.76 mL, 5.14 mmol) and allylmagnesium chloride (2.0 M in Et₂O, 5.0 mL, 10.0 mmol) in ether (20 mL) was refluxed under a nitrogen atmosphere for 16 h. This was cooled to room temperature and was quenched with saturated aqueous NH₄Cl (50 mL). The organic layer was separated, and the aqueous layer was extracted with additional ether (3 × 25 mL). The combined organic layer was washed with brine (50 mL), dried over MgSO₄, and concentrated in vacuo at 0°C. The crude product was purified by radial chromatography (pentane) to afford **6a** (0.90 g, 4.50 mmol, 88%) as a clear, colorless oil. ¹H NMR (CDCl₃) δ: 2.35–2.43 (2H, m), 2.77 (2H, t, *J* = 8.1 Hz), 4.97–5.08 (2H, m), 5.84 (1H, ddt, *J*₁ = 9.9 Hz, *J*₂ = 7.2 Hz, *J*₃ = 6.9 Hz), 7.29 (2H, d, *J* = 7.8 Hz), 7.53 (2H, d, *J* = 7.8 Hz). ¹³C NMR (CDCl₃) δ: 35.0, 35.1, 115.4, 124.4 (q, *J*_{C-F} = 270.2 Hz), 125.2 (2C, *J*_{C-F} = 3.3 Hz), 128.2 (q, *J*_{C-F} = 32.0 Hz), 128.8 (2C), 147.7, 145.9. HRMS calcd. for C₁₁H₁₁F₃: 200.0813; found: 200.0810.

4-(3-(Trifluoromethyl)phenyl)but-1-ene (6b) was prepared by procedure H, from 3-(trifluoromethyl)benzyl chloride (0.80 mL, 5.16 mmol) and allylmagnesium chloride (5.0 mL, 10.0 mmol), in 85% yield (0.89 g, 4.40 mmol). ¹H NMR (CDCl₃) δ: 2.36–2.44 (2H, m), 2.78 (2H, dd, *J*₁ = 8.1 Hz, *J*₂ = 6.3 Hz), 4.99–5.09 (2H, m), 5.85 (1H, ddt, *J*₁ = 10.5 Hz, *J*₂ = 6.6 Hz, *J*₃ = 6.3 Hz), 7.35–7.47 (4H, m). ¹³C NMR (CDCl₃) δ: 35.2, 35.2, 115.4, 122.7 (q, *J*_{C-F} = 3.3 Hz), 124.3 (q, *J*_{C-F} = 270.2 Hz), 125.2 (q, *J*_{C-F} = 3.3 Hz), 128.6, 130.5 (q, *J*_{C-F} = 32.0 Hz), 131.8, 137.3, 142.6. HRMS calcd. for C₁₁H₁₁F₃: 200.0813; found: 200.0808.

4-(4-Fluorophenyl)but-1-ene (6c) was prepared by procedure H, from 4-fluorobenzyl bromide (1 mL, 8.04 mmol) and allylmagnesium chloride (6.0 mL, 12.0 mmol), in 79% yield (0.96 g, 6.39 mmol). ¹H NMR (CDCl₃) δ: 2.34–2.42 (2H, m), 2.71 (2H, dd, *J*₁ = 8.1 Hz, *J*₂ = 7.5 Hz), 4.99–5.10 (2H, m), 5.87 (1H, ddt, *J*₁ = 10.5 Hz, *J*₂ = 6.6 Hz, *J*₃ = 6.3 Hz), 6.95–7.03 (2H, m), 7.13–7.19 (2H, m). ¹³C NMR (CDCl₃) δ: 34.5, 35.6, 114.9 (2C, d, *J*_{C-F} = 20.2 Hz), 115.1, 129.8 (2C, d, *J*_{C-F} = 7.7 Hz), 137.4 (d, *J*_{C-F} = 2.3 Hz), 137.8, 161.3 (d, *J*_{C-F} = 241.6 Hz). HRMS calcd. for C₁₀H₁₁F: 150.0845; found: 150.0840.

4-(3-Fluorophenyl)but-1-ene (6d) was prepared by procedure H from 3-fluorobenzyl bromide (1 mL, 8.15 mmol) and allylmagnesium chloride (6.0 mL, 12.0 mmol), in 78% yield (0.95 g, 6.32 mmol). ^1H NMR (CDCl_3) δ : 2.39–2.47 (2H, m), 2.76 (2H, dd, $J_1 = 8.1$ Hz, $J_2 = 6.3$ Hz), 5.03–5.14 (2H, m), 5.90 (1H, ddt, $J_1 = 9.9$ Hz, $J_2 = 6.9$ Hz, $J_3 = 6.6$ Hz), 6.90–7.02 (3H, m), 7.24–7.32 (1H, m). ^{13}C NMR (CDCl_3) δ : 35.1, 35.2, 112.7 (d, $J_{\text{C-F}} = 21.0$ Hz), 115.2 (d, $J_{\text{C-F}} = 20.9$ Hz), 115.3, 124.1 (d, $J_{\text{C-F}} = 2.3$ Hz), 129.6 (d, $J_{\text{C-F}} = 7.7$ Hz), 137.6, 144.4 (d, $J_{\text{C-F}} = 6.6$ Hz), 162.9 (d, $J_{\text{C-F}} = 243.8$ Hz). HRMS calcd. for $\text{C}_{10}\text{H}_{11}\text{F}$: 150.0845; found: 150.0849.

4-(4-Methylphenyl)but-1-ene (6e) was prepared by procedure H, from 4-methylbenzyl bromide (1.10 g, 5.94 mmol) and allylmagnesium chloride (4.0 mL, 8.0 mmol), in 61% yield (0.53 g, 3.62 mmol). ^1H NMR (CDCl_3) δ : 2.50 (3H, s), 2.52–2.59 (2H, m), 2.85 (2H, dd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz), 5.15–5.27 (2H, m), 6.05 (1H, ddt, $J_1 = 10.5$ Hz, $J_2 = 6.6$ Hz, $J_3 = 6.3$ Hz), 7.27 (4H, s). ^{13}C NMR (CDCl_3) δ : 21.1, 35.1, 35.8, 114.9, 128.4 (2C), 129.1 (2C), 135.3, 138.3, 138.9. HRMS calcd. for $\text{C}_{11}\text{H}_{14}$: 146.1096; found: 146.1100.

4-(3-Methylphenyl)but-1-ene (6f) was prepared by procedure H, from 3-methylbenzyl bromide (1.10 g, 5.94 mmol) and allylmagnesium chloride (4.0 mL, 8.0 mmol), in 62% yield (0.54 g, 3.69 mmol). ^1H NMR (CDCl_3) δ : 2.41 (3H, s), 2.43–2.49 (2H, m), 2.75 (2H, dd, $J_1 = 8.1$ Hz, $J_2 = 5.7$ Hz), 5.04–5.17 (2H, m), 5.95 (1H, ddt, $J_1 = 10.2$, $J_2 = 6.9$ Hz, $J_3 = 6.6$ Hz), 7.07–7.28 (4H, m). ^{13}C NMR (CDCl_3) δ : 21.4, 35.4, 35.6, 114.8, 125.5, 126.6, 128.2, 129.3, 137.8, 138.2, 141.9. HRMS calcd. for $\text{C}_{11}\text{H}_{14}$: 146.1096; found: 146.1096.

4-(4-Methoxyphenyl)but-1-ene (6g) was prepared by procedure H, from 4-methoxybenzyl chloride (0.60 mL, 4.43 mmol) and allylmagnesium chloride (4.0 mL, 8.0 mmol), in 97% yield (0.70 g, 4.31 mmol). ^1H NMR (CDCl_3) δ : 2.31 (2H, m), 2.65 (2H, dd, $J_1 = 8.1$ Hz, $J_2 = 6.0$ Hz), 3.79 (3H, s), 4.95–5.08 (2H, m), 5.85 (1H, ddt, $J_1 = 10.5$, $J_2 = 6.6$ Hz, $J_3 = 6.3$ Hz), 6.83 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 2.7$ Hz), 7.10 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 2.4$ Hz). ^{13}C NMR (CDCl_3) δ : 34.6, 35.9, 55.2, 113.8 (2C), 114.9, 129.4 (2C), 134.0, 138.2, 157.9. HRMS calcd. for $\text{C}_{11}\text{H}_{14}\text{O}$: 162.1045; found: 162.1047.

4-(3-Methoxyphenyl)but-1-ene (6h) was prepared by procedure H, from 3-methoxybenzyl chloride (0.60 mL, 4.13 mmol) and allylmagnesium chloride (4.0 mL, 8.00 mmol), in 84% yield (0.56 g, 3.45 mmol). ^1H NMR (CDCl_3) δ : 2.34–2.42 (2H, m), 2.69 (2H, dd, $J_1 = 8.1$ Hz, $J_2 = 6.0$ Hz), 3.81 (3H, s), 4.96–5.09 (2H, m), 5.87 (1H, ddt, $J_1 = 10.5$, $J_2 = 6.6$ Hz, $J_3 = 6.3$ Hz), 6.73–6.81 (3H, s), 7.18–7.24 (1H, m). ^{13}C NMR (CDCl_3) δ : 35.4, 35.5, 55.1, 111.1, 114.3, 115.0, 120.9, 129.3, 138.1, 143.5, 159.7. HRMS calcd. for $\text{C}_{11}\text{H}_{14}\text{O}$: 162.1045; found: 162.1040.

***N*-Methoxy-*N*-methyl-*trans*-4-(trifluoromethyl)cinnamamide (8a). Procedure A**

A solution of 4-(trifluoromethyl)benzaldehyde (10.0 g, 57.4 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (23.1 g, 63.6 mmol) in CH_2Cl_2 (150 mL) was stirred at room temperature for 16 h. The solvent was then removed in vacuo, and the crude product was

chromatographed on silica gel (40% ethyl acetate in hexanes) to afford **8a** (14.1 g, 54.3 mmol, 95%) as a white solid; mp 50–52°C. ^1H NMR (CDCl_3) δ : 3.32 (3H, s), 3.78 (3H, s), 7.10 (1H, d, $J = 15.9$ Hz), 7.65 (4H, dd, $J_1 = 12.0$ Hz, $J_2 = 9.0$ Hz), 7.74 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.5, 61.9, 118.4, 123.8 (q, $J_{\text{C-F}} = 276.9$ Hz), 125.6 (2C, q, $J_{\text{C-F}} = 3.7$ Hz), 128.1 (2C), 131.3 (q, $J_{\text{C-F}} = 33.1$ Hz), 138.6, 141.5, 166.2. HRMS calcd. for $\text{C}_{12}\text{H}_{12}\text{F}_3\text{NO}_2$: 259.0820; found: 259.0820.

***N*-Methoxy-*N*-methyl-*trans*-3-(trifluoromethyl)cinnamamide (8b)** was prepared by procedure A, using 3-(trifluoromethyl)benzaldehyde (3.20 mL, 23.9 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (10.0 g, 27.5 mmol), in 99% yield (6.15 g, 23.7 mmol). ^1H NMR (CDCl_3) δ : 3.23 (3H, s), 3.70 (3H, s), 7.02 (1H, d, $J = 15.9$ Hz), 7.38–7.71 (4H, m), 7.65 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.3, 61.8, 117.7, 123.8 (q, $J_{\text{C-F}} = 271.4$ Hz), 124.2 (q, $J_{\text{C-F}} = 3.3$ Hz), 126.0 (q, $J_{\text{C-F}} = 3.3$ Hz), 129.3, 131.1, 131.1 (q, $J_{\text{C-F}} = 32.0$ Hz), 135.9, 141.5, 166.1. HRMS calcd. for $\text{C}_{12}\text{H}_{12}\text{F}_3\text{NO}_2$: 259.0820; found: 259.0825.

***N*-Methoxy-*N*-methyl-*trans*-4-fluorocinnamamide (8c)** was prepared by procedure A, using 4-fluorobenzaldehyde (4.40 mL, 42.0 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (17.30 g, 47.6 mmol), in 99% yield (8.68 g, 41.5 mmol). ^1H NMR (CDCl_3) δ : 3.24 (3H, s), 3.70 (3H, s), 6.90 (1H, d, $J = 15.9$ Hz), 6.97–7.04 (2H, m), 7.46–7.51 (2H, m), 7.63 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.4, 61.8, 115.5, 115.7 (2C, d, $J_{\text{C-F}} = 22.1$ Hz), 129.7 (2C, d, $J_{\text{C-F}} = 8.9$ Hz), 131.3 (d, $J_{\text{C-F}} = 3.3$ Hz), 142.0, 163.5 (d, $J_{\text{C-F}} = 249.2$ Hz), 166.7. HRMS calcd. for $\text{C}_{11}\text{H}_{12}\text{FNO}_2$: 209.0852; found: 209.0855.

***N*-Methoxy-*N*-methyl-*trans*-3-fluorocinnamamide (8d)** was prepared by procedure A, using 3-fluorobenzaldehyde (1.80 mL, 17.4 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (7.50 g, 20.6 mmol), in 98% yield (3.58 g, 17.1 mmol). ^1H NMR (CDCl_3) δ : 3.24 (3H, s), 3.70 (3H, s), 6.95–7.01 (1H, m), 6.97 (1H, d, $J = 15.9$ Hz), 7.17–7.31 (3H, m), 7.61 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.4, 61.8, 114.0 (d, $J_{\text{C-F}} = 20.9$ Hz), 116.6 (d, $J_{\text{C-F}} = 21.0$ Hz), 117.1, 124.1, 130.2 (d, $J_{\text{C-F}} = 7.7$ Hz), 137.3 (d, $J_{\text{C-F}} = 7.7$ Hz), 141.9 (d, $J_{\text{C-F}} = 2.2$ Hz), 162.9 (d, $J_{\text{C-F}} = 244.8$ Hz), 166.4. HRMS calcd. for $\text{C}_{11}\text{H}_{12}\text{FNO}_2$: 209.0852; found: 209.0855.

***N*-Methoxy-*N*-methyl-*trans*-4-methylcinnamamide (8e)** was prepared by procedure A, using 4-methylbenzaldehyde (3.0 mL, 25.5 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (11.50 g, 31.6 mmol), in 100% yield (5.24 g, 25.5 mmol); mp 52–53°C. ^1H NMR (CDCl_3) δ : 2.37 (3H, s), 3.30 (3H, s), 3.76 (3H, s), 6.97 (1H, d, $J = 15.9$ Hz), 7.18 (2H, d, $J = 8.1$ Hz), 4.47 (2H, d, $J = 8.1$ Hz), 7.71 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 21.4, 32.5, 61.8, 114.7, 128.0 (2C), 129.5 (2C), 132.4, 140.1, 143.4, 167.2. HRMS calcd. for $\text{C}_{12}\text{H}_{15}\text{NO}_2$: 205.1103; found: 205.1109.

***N*-Methoxy-*N*-methyl-*trans*-3-methylcinnamamide (8f)** was prepared by procedure A, using 3-methylbenzaldehyde (3.0 mL, 25.5 mmol) and *N*-methoxy-*N*-methyl-2-

(triphenylphosphoranylidene)acetamide (11.5 g, 31.6 mmol), in 97% yield (5.06 g, 24.7 mmol). ^1H NMR (CDCl_3) δ : 2.35 (3H, s), 3.28 (3H, s), 3.74 (3H, s), 7.01 (1H, d, $J = 15.9$ Hz), 7.13–7.35 (4H, m), 7.69 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 21.3, 32.5, 61.8, 115.6, 125.2, 128.6, 128.7, 130.6, 135.1, 138.4, 143.5, 167.0. HRMS calcd. for $\text{C}_{12}\text{H}_{15}\text{NO}_2$: 205.1103; found: 205.1107.

***N*-Methoxy-*N*-methyl-*trans*-4-methoxycinnamamide (8g)** was prepared by procedure A, using 4-methoxybenzaldehyde (3.0 mL, 24.7 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (10.0 g, 27.5 mmol), in 92% yield (5.03 g, 22.7 mmol). ^1H NMR (CDCl_3) δ : 3.27 (3H, s), 3.72 (3H, s), 3.79 (3H, s), 6.86 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 1.8$ Hz), 6.88 (1H, d, $J = 15.9$ Hz), 7.48 (2H, dt, $J_1 = 9.0$ Hz, $J_2 = 2.4$ Hz), 7.67 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.4, 55.3, 61.7, 113.3, 114.2 (2C), 127.8, 129.6 (2C), 143.0, 161.0, 167.2. HRMS calcd. for $\text{C}_{12}\text{H}_{15}\text{NO}_3$: 221.1052; found: 221.1052.

***N*-Methoxy-*N*-methyl-*trans*-3-methoxycinnamamide (8h)** was prepared by procedure A, using 3-methoxybenzaldehyde (4.0 mL, 32.9 mmol) and *N*-methoxy-*N*-methyl-2-(triphenylphosphoranylidene)acetamide (12.50 g, 34.4 mmol), in 98% yield (7.11 g, 32.1 mmol). ^1H NMR (CDCl_3) δ : 3.24 (3H, s), 3.69 (3H, s), 3.76 (3H, s), 6.83–7.26 (3H, m), 6.97 (1H, d, $J = 15.9$ Hz), 7.23 (1H, t, $J = 7.8$ Hz), 7.64 (1H, d, $J = 15.9$ Hz). ^{13}C NMR (CDCl_3) δ : 32.4, 55.2, 61.8, 113.3, 115.3, 116.1, 120.5, 129.7, 136.5, 143.2, 159.8, 166.7. HRMS calcd. for $\text{C}_{12}\text{H}_{15}\text{NO}_3$: 221.1052; found: 221.1058.

***N*-Methoxy-*N*-methyl-*trans*-2-(4-(trifluoromethyl)phenyl)cyclopropanecarboxamide (9a). Procedure B**

A solution of trimethylsulfoxonium iodide (24.1 g, 110 mmol) in DMSO (100 mL) under a nitrogen atmosphere was cooled with a room-temperature water bath, and NaH (2.6 g, 108 mmol) was added portionwise over 15 min. After the addition was complete, the suspension was allowed to stir for 1 h, during which time it became homogeneous. A solution of **8a** (14.1 g, 54.3 mmol) in DMSO (50 mL) was added via cannula, and the reaction mixture was stirred for 6 h. The reaction mixture was quenched by pouring it into saturated aqueous NH_4Cl solution (500 mL). The mixture was extracted with CH_2Cl_2 (3 \times 250 mL). The combined organic layer was washed with brine (200 mL), dried over MgSO_4 , filtered, and concentrated in vacuo. The crude material was chromatographed on silica gel (40% ethyl acetate in hexanes) to afford **9a** (12.8 g, 46.8 mmol, 86%) as a clear, colorless oil. ^1H NMR (CDCl_3) δ : 1.30 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.5$ Hz), 1.65 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.38–2.46 (1H, m), 2.50 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.2$ Hz), 3.19 (3H, s), 3.65 (3H, s), 7.18 (2H, d, $J = 9.0$ Hz), 7.48 (2H, d, $J = 9.0$ Hz). ^{13}C NMR (CDCl_3) δ : 16.5, 21.8, 25.2, 32.4, 61.5, 124.1 (q, $J_{\text{C-F}} = 270.3$ Hz), 125.2 (2C, q, $J_{\text{C-F}} = 3.3$ Hz), 126.3 (2C), 128.3 (q, $J_{\text{C-F}} = 32.4$ Hz), 145.0, 172.2. HRMS calcd. for $\text{C}_{13}\text{H}_{14}\text{F}_3\text{NO}_2$: 273.0977; found: 273.0974.

***N*-Methoxy-*N*-methyl-*trans*-2-(3-(trifluoromethyl)phenyl)cyclopropanecarboxamide (9b)** was prepared by procedure B, using **8b** (6.15 g, 23.7 mmol), trimethylsulfoxonium iodide (10.50 g, 47.7 mmol), and NaH (1.15 g, 47.9 mmol),

in 87% yield (5.55 g, 20.3 mmol). ^1H NMR (CDCl_3) δ : 1.26 (1H, ddd, $J_1 = 8.7$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.8$ Hz), 1.60 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.34–2.44 (1H, m), 2.50 (1H, ddd, $J_1 = 8.7$ Hz, $J_2 = 6.0$ Hz, $J_3 = 4.2$ Hz), 3.16 (3H, s), 3.62 (3H, s), 7.22–7.37 (4H, m). ^{13}C NMR (CDCl_3) δ : 16.3, 21.6, 25.2, 32.4, 61.5, 122.9 (q, $J_{\text{C-F}} = 3.3$ Hz), 123.0 (q, $J_{\text{C-F}} = 3.3$ Hz), 124.1 (q, $J_{\text{C-F}} = 270.2$ Hz), 128.8, 129.6, 130.6 (q, $J_{\text{C-F}} = 30.9$ Hz), 141.9, 172.3. HRMS calcd. for $\text{C}_{13}\text{H}_{14}\text{F}_3\text{NO}_2$: 273.0977; found: 273.0983.

***N*-Methoxy-*N*-methyl-*trans*-2-(4-fluorophenyl)cyclopropanecarboxamide (9c)** was prepared by procedure B, using **8c** (8.50 g, 40.6 mmol), trimethylsulfoxonium iodide (17.90 g, 81.3 mmol), and NaH (1.95 g, 81.3 mmol), in 88% yield (7.95 g, 35.6 mmol). ^1H NMR (CDCl_3) δ : 1.21 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.2$ Hz), 1.57 (1H, ddd, $J_1 = 9.6$ Hz, $J_2 = 5.7$ Hz, $J_3 = 4.5$ Hz), 2.26–2.36 (1H, m), 2.44 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.2$ Hz), 3.19 (3H, s), 3.65 (3H, s), 6.87–6.95 (2H, m), 7.01–7.08 (2H, m). ^{13}C NMR (CDCl_3) δ : 16.2, 21.4, 25.0, 32.5, 61.6, 115.2 (d, $J_{\text{C-F}} = 20.9$ Hz), 127.7 (d, $J_{\text{C-F}} = 7.7$ Hz), 136.4 (d, $J_{\text{C-F}} = 3.3$ Hz), 161.4 (d, $J_{\text{C-F}} = 242.6$ Hz), 172.8. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{FNO}_2$: 223.1009; found: 223.1013.

***N*-Methoxy-*N*-methyl-*trans*-2-(3-fluorophenyl)cyclopropanecarboxamide (9d)** was prepared by procedure B, using **8d** (3.19 g, 15.2 mmol), trimethylsulfoxonium iodide (6.70 g, 30.4 mmol), and NaH (0.73 g, 30.4 mmol), in 85% yield (2.87 g, 12.9 mmol). ^1H NMR (CDCl_3) δ : 1.26 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.5$ Hz), 1.61 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 5.7$ Hz, $J_3 = 4.5$ Hz), 2.35–2.42 (1H, m), 2.45 (1H, ddd, $J_1 = 10.5$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.5$ Hz), 3.20 (3H, s), 3.67 (3H, s), 6.75–6.91 (3H, m), 7.16–7.23 (1H, m). ^{13}C NMR (CDCl_3) δ : 16.5, 21.7, 25.4, 32.5, 61.6, 112.8 (d, $J_{\text{C-F}} = 20.8$ Hz), 113.1 (d, $J_{\text{C-F}} = 20.8$ Hz), 122.0 (d, $J_{\text{C-F}} = 2.2$ Hz), 129.8 (d, $J_{\text{C-F}} = 7.7$ Hz), 143.5 (d, $J_{\text{C-F}} = 7.7$ Hz), 162.9 (d, $J_{\text{C-F}} = 243.8$ Hz), 172.5. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{FNO}_2$: 223.1009; found: 223.1015.

***N*-Methoxy-*N*-methyl-*trans*-2-(4-methylphenyl)cyclopropanecarboxamide (9e)** was prepared by procedure B, using **8e** (10.15 g, 49.4 mmol), trimethylsulfoxonium iodide (21.75 g, 98.8 mmol), and NaH (2.37 g, 98.8 mmol), in 78% yield (8.43 g, 38.4 mmol); mp 72–73°C. ^1H NMR (CDCl_3) δ : 1.28 (1H, ddd, $J_1 = 8.1$ Hz, $J_2 = 6.0$ Hz, $J_3 = 4.2$ Hz), 1.62 (1H, ddd, $J_1 = 9.6$ Hz, $J_2 = 5.7$ Hz, $J_3 = 4.5$ Hz), 2.32 (3H, s), 2.34–2.42 (1H, m), 2.48 (1H, ddd, $J_1 = 8.7$ Hz, $J_2 = 6.0$ Hz, $J_3 = 3.9$ Hz), 3.23 (3H, s), 3.68 (3H, s), 7.03 (2H, d, $J = 8.4$ Hz), 7.09 (2H, d, $J = 8.4$ Hz). ^{13}C NMR (CDCl_3) δ : 16.3, 21.0, 21.5, 25.7, 32.6, 61.6, 126.1 (2C), 129.1 (2C), 135.8, 137.7, 173.1. HRMS calcd. for $\text{C}_{13}\text{H}_{17}\text{NO}_2$: 219.1259; found: 219.1261.

***N*-Methoxy-*N*-methyl-*trans*-2-(3-methylphenyl)cyclopropanecarboxamide (9f)** was prepared by procedure B, using **8f** (10.12 g, 49.3 mmol), trimethylsulfoxonium iodide (21.70 g, 98.6 mmol), and NaH (2.30 g, 95.8 mmol), in 89% yield (9.65 g, 44.0 mmol). ^1H NMR (CDCl_3) δ : 1.30 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.2$ Hz), 1.62 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 5.7$ Hz, $J_3 = 4.5$ Hz), 2.33 (3H, s), 2.38–2.45 (1H, m), 2.48 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 6.3$ Hz, $J_3 =$

4.2 Hz), 3.23 (3H, s), 3.69 (3H, s), 6.92–7.19 (4H, m). ^{13}C NMR (CDCl_3) δ : 16.4, 21.4, 21.5, 25.9, 32.6, 61.7, 123.2, 127.0, 127.1, 128.3, 138.0, 140.7, 173.0. HRMS calcd. for $\text{C}_{13}\text{H}_{17}\text{NO}_2$: 219.1259; found: 219.1261.

***N*-Methoxy-*N*-methyl-*trans*-2-(4-methoxyphenyl)cyclopropanecarboxamide (9g)** was prepared by procedure B, using **8g** (5.03 g, 23.7 mmol), trimethylsulfoxonium iodide (10.0 g, 45.4 mmol), and NaH (1.10 g, 45.8 mmol), in 86% yield (4.61 g, 19.6 mmol). ^1H NMR (CDCl_3) δ : 1.25 (1H, ddd, $J_1 = 8.1$ Hz, $J_2 = 6.3$ Hz, $J_3 = 3.9$ Hz), 1.58 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.28–2.36 (1H, m), 2.46 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.2$ Hz), 3.23 (3H, s), 3.69 (3H, s), 3.78 (3H, s), 6.82 (2H, dt, $J_1 = 9.0$ Hz, $J_2 = 2.4$ Hz), 7.07 (2H, dt, $J_1 = 8.4$ Hz, $J_2 = 1.8$ Hz). ^{13}C NMR (CDCl_3) δ : 16.0, 21.3, 25.3, 32.5, 55.2, 61.6, 113.8 (2C), 127.3 (2C), 132.6, 158.2, 173.1. HRMS calcd. for $\text{C}_{13}\text{H}_{17}\text{NO}_3$: 235.1208; found: 235.1205.

***N*-Methoxy-*N*-methyl-*trans*-2-(3-methoxyphenyl)cyclopropanecarboxamide (9h)** was prepared by procedure B, using **8h** (4.77 g, 21.6 mmol), trimethylsulfoxonium iodide (9.50 g, 43.0 mmol), and NaH (1.04 g, 43.3 mmol), in 92% yield (4.69 g, 19.9 mmol). ^1H NMR (CDCl_3) δ : 1.26 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.2$ Hz), 1.58 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.34–2.48 (2H, m), 3.19 (3H, s), 3.64 (3H, s), 3.74 (3H, s), 6.65–6.72 (3H, m), 7.15 (1H, t, $J = 8.1$ Hz). ^{13}C NMR (CDCl_3) δ : 16.4, 21.6, 25.9, 32.5, 55.1, 61.6, 111.4, 112.2, 118.4, 129.4, 142.4, 159.7, 172.9. HRMS calcd. for $\text{C}_{13}\text{H}_{17}\text{NO}_3$: 235.1208; found: 235.1205.

***trans*-2-(4-(Trifluoromethyl)phenyl)cyclopropanecarboxylic acid (10a). Procedure C**

A suspension of **9a** (7.71 g, 28.2 mmol) and potassium *tert*-butoxide (17.11 g, 152 mmol) in ether (200 mL) and water (1.0 mL, 55.6 mmol) was stirred at room temperature for 16 h. The mixture was acidified by the slow addition of concentrated HCl, and the aqueous mixture was extracted with CH_2Cl_2 (3 \times 200 mL). The combined organic layer was washed with brine (200 mL), dried over Na_2SO_4 , filtered, and concentrated in vacuo to afford **10a** (5.85 g, 25.4 mmol, 90%) as a white solid; mp 110–111°C. ^1H NMR (CDCl_3) δ : 1.45 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.8$ Hz), 1.73 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 1.96 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.65 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.6$ Hz, $J_3 = 3.9$ Hz), 7.21 (2H, d, $J = 8.4$ Hz), 7.55 (2H, d, $J = 8.4$ Hz), 12.08 (1H, bs). ^{13}C NMR (CDCl_3) δ : 17.6, 24.2, 26.5, 124.1 (q, $J_{\text{C-F}} = 270.2$ Hz), 125.5 (2C, q, $J_{\text{C-F}} = 3.3$ Hz), 126.5 (2C), 129.0 (q, $J_{\text{C-F}} = 33.1$ Hz), 143.6, 179.4. HRMS calcd. for $\text{C}_{11}\text{H}_9\text{F}_3\text{O}_2$: 230.0555; found: 230.0560.

***trans*-2-(3-(Trifluoromethyl)phenyl)cyclopropanecarboxylic acid (10b)** was prepared by procedure C, using **9b** (2.42 g, 8.86 mmol), potassium *tert*-butoxide (5.97 g, 53.2 mmol), and water (0.34 mL, 18.9 mmol), in 95% yield (1.94 g, 8.42 mmol); mp 61–62°C. ^1H NMR (CDCl_3) δ : 1.45 (1H, ddd, $J_1 = 8.1$ Hz, $J_2 = 6.3$ Hz, $J_3 = 4.5$ Hz), 1.73 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 1.95 (1H, ddd, $J_1 = 8.1$ Hz, $J_2 = 5.1$ Hz, $J_3 = 3.9$ Hz), 2.67 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 6.3$ Hz, $J_3 = 3.9$ Hz), 7.28–7.50 (4H, m), 12.35 (1H, bs). ^{13}C

NMR (CDCl_3) δ : 17.4, 24.0, 26.6, 123.1 (q, $J_{\text{C-F}} = 3.3$ Hz), 123.5 (q, $J_{\text{C-F}} = 3.3$ Hz), 124.0 (q, $J_{\text{C-F}} = 270.2$ Hz), 129.0, 129.7, 130.9 (q, $J_{\text{C-F}} = 32.0$ Hz), 140.5, 179.6. HRMS calcd. for $\text{C}_{11}\text{H}_9\text{F}_3\text{O}_2$: 230.0555; found: 230.0560.

***trans*-2-(4-Fluorophenyl)cyclopropanecarboxylic acid (10c)** was prepared by procedure C, using **9c** (7.67 g, 34.4 mmol), potassium *tert*-butoxide (23.13 g, 206 mmol), and water (1.20 mL, 66.7 mmol), in 93% yield (5.77 g, 32.0 mmol); mp 107–108°C. ^1H NMR (CDCl_3) δ : 1.37 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.5$ Hz), 1.66 (1H, dt, $J_1 = 9.6$ Hz, $J_2 = 4.8$ Hz), 1.85 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 5.4$ Hz, $J_3 = 4.2$ Hz), 2.60 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.6$ Hz, $J_3 = 3.9$ Hz), 6.94–7.01 (2H, m), 7.05–7.12 (2H, m) 11.53 (1H, bs). ^{13}C NMR (CDCl_3) δ : 17.3, 23.8, 26.4, 115.3 (2C, d, $J_{\text{C-F}} = 22.1$ Hz), 127.9 (2C, d, $J_{\text{C-F}} = 7.7$ Hz), 135.1 (d, $J_{\text{C-F}} = 2.2$ Hz), 161.7 (d, $J_{\text{C-F}} = 243.8$ Hz), 179.8. HRMS calcd. for $\text{C}_{10}\text{H}_9\text{FO}_2$: 180.0587; found: 180.0591.

***trans*-2-(3-Fluorophenyl)cyclopropanecarboxylic acid (10d)** was prepared by procedure C, using **9d** (2.87 g, 12.9 mmol), potassium *tert*-butoxide (8.00 g, 71.3 mmol), and water (0.40 mL, 22.2 mmol), in 98% yield (2.27 g, 12.6 mmol); mp 76–77°C. ^1H NMR (CDCl_3) δ : 1.39 (1H, ddd, $J_1 = 8.7$ Hz, $J_2 = 6.9$ Hz, $J_3 = 5.1$ Hz), 1.68 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.4$ Hz), 1.91 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 5.4$ Hz, $J_3 = 3.9$ Hz), 2.60 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.2$ Hz), 6.79 (1H, dt, $J_1 = 9.9$ Hz, $J_2 = 2.1$ Hz), 6.88–6.95 (2H, m) 7.25 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 6.0$ Hz), 10.31 (1H, bs). ^{13}C NMR (CDCl_3) δ : 17.5, 24.0, 26.6, 113.2 (d, $J_{\text{C-F}} = 22.1$ Hz), 113.6 (d, $J_{\text{C-F}} = 22.1$ Hz), 122.0 (d, $J_{\text{C-F}} = 3.3$ Hz), 129.9 (d, $J_{\text{C-F}} = 7.7$ Hz), 142.1 (d, $J_{\text{C-F}} = 7.7$ Hz), 161.6 (d, $J_{\text{C-F}} = 243.8$ Hz), 179.4. HRMS calcd. for $\text{C}_{10}\text{H}_9\text{FO}_2$: 180.0587; found: 180.0589.

***trans*-2-(4-Methylphenyl)cyclopropanecarboxylic acid (10e)** was prepared by procedure C, using **9e** (8.20 g, 37.4 mmol), potassium *tert*-butoxide (25.18 g, 224 mmol), and water (1.35 mL, 75.0 mmol), in 98% yield (6.43 g, 36.5 mmol); mp 118–119°C. ^1H NMR (CDCl_3) δ : 1.39 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 6.9$ Hz, $J_3 = 4.5$ Hz), 1.65 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 1.87 (1H, ddd, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz, $J_3 = 4.2$ Hz), 2.33 (3H, s), 2.59 (1H, ddd, $J_1 = 9.0$ Hz, $J_2 = 6.6$ Hz, $J_3 = 3.9$ Hz), 7.02 (2H, d, $J = 8.1$ Hz), 7.10 (2H, d, $J = 8.1$ Hz), 10.62 (1H, bs). ^{13}C NMR (CDCl_3) δ : 17.4, 21.0, 23.9, 26.9, 126.2 (2C), 129.2 (2C), 136.3, 136.4, 180.0. HRMS calcd. for $\text{C}_{11}\text{H}_{12}\text{O}_2$: 176.0837; found: 176.0841.

***trans*-2-(3-Methylphenyl)cyclopropanecarboxylic acid (10f)** was prepared by procedure C, using **9f** (9.22 g, 42.0 mmol), potassium *tert*-butoxide (28.25 g, 252 mmol), and water (1.50 mL, 83.3 mmol), in 94% yield (6.96 g, 39.5 mmol); mp 87–88°C. ^1H NMR (CDCl_3) δ : 1.41 (1H, ddd, $J_1 = 8.1$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.5$ Hz), 1.66 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.5$ Hz), 1.91 (1H, ddd, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz, $J_3 = 4.2$ Hz), 2.34 (3H, s), 2.58 (1H, ddd, $J_1 = 9.3$ Hz, $J_2 = 6.6$ Hz, $J_3 = 4.2$ Hz), 6.91–7.26 (4H, m), 10.44 (1H, bs). ^{13}C NMR (CDCl_3) δ : 17.4, 21.3, 23.9, 27.1, 123.3, 127.1, 127.5, 128.4, 138.2, 139.4, 179.9. HRMS calcd. for $\text{C}_{11}\text{H}_{12}\text{O}_2$: 176.0837; found: 176.0839.

***trans*-2-(4-Methoxyphenyl)cyclopropanecarboxylic acid (10g)** was prepared by procedure C, using **9g** (4.60 g, 19.6 mmol), potassium *tert*-butoxide (13.50 g, 120 mmol), and water (0.75 mL, 41.7 mmol), in 96% yield (3.62 g, 18.8 mmol); mp 112–113°C. ¹H NMR (CDCl₃) δ: 1.35 (1H, ddd, *J*₁ = 8.1 Hz, *J*₂ = 6.6 Hz, *J*₃ = 4.5 Hz), 1.62 (1H, dt, *J*₁ = 9.6 Hz, *J*₂ = 5.1 Hz), 1.82 (1H, ddd, *J*₁ = 8.1 Hz, *J*₂ = 4.8 Hz, *J*₃ = 3.9 Hz), 2.57 (1H, ddd, *J*₁ = 9.6 Hz, *J*₂ = 6.9 Hz, *J*₃ = 4.5 Hz), 3.79 (3H, s), 6.83 (2H, dt, *J*₁ = 9.0 Hz, *J*₂ = 2.4 Hz), 7.04 (2H, dt, *J*₁ = 8.7 Hz, *J*₂ = 2.1 Hz), 10.55 (1H, bs). ¹³C NMR (CDCl₃) δ: 17.2, 23.7, 26.6, 55.3, 114.0 (2C), 127.5 (2C), 131.4, 158.5, 179.7. HRMS calcd. for C₁₁H₁₂O₃: 192.0786; found: 192.0782.

***trans*-2-(3-Methoxyphenyl)cyclopropanecarboxylic acid (10h)** was prepared by procedure C, using **9h** (3.79 g, 16.1 mmol), potassium *tert*-butoxide (10.85 g, 96.7 mmol), and water (0.60 mL, 33.3 mmol), in 97% yield (2.99 g, 15.6 mmol); mp 93–94°C. ¹H NMR (CDCl₃) δ: 1.40 (1H, ddd, *J*₁ = 8.4 Hz, *J*₂ = 6.6 Hz, *J*₃ = 4.8 Hz), 1.65 (1H, dt, *J*₁ = 9.6 Hz, *J*₂ = 5.1 Hz), 1.90 (1H, ddd, *J*₁ = 8.7 Hz, *J*₂ = 5.1 Hz, *J*₃ = 3.9 Hz), 2.58 (1H, ddd, *J*₁ = 9.9 Hz, *J*₂ = 6.6 Hz, *J*₃ = 4.2 Hz), 3.79 (3H, s), 6.45–6.78 (3H, m), 7.20 (1H, t, *J* = 8.1 Hz), acid OH not observed. ¹³C NMR (CDCl₃) δ: 17.5, 24.0, 27.1, 55.2, 112.0, 112.2, 118.5, 129.6, 141.2, 159.7, 180.0. HRMS calcd. for C₁₁H₁₂O₃: 192.0786; found: 192.0783.

***trans*-2-(4-(Trifluoromethyl)phenyl)cyclopropylmethanol (13a). Procedure D**

A solution of **10a** (2.00 g, 8.69 mmol) in THF (75 mL) under a nitrogen atmosphere was cooled to 0°C, and LiAlH₄ (0.70 g, 18.4 mmol) was added. The mixture was stirred for 2 h, after which time the reaction mixture was quenched by the sequential addition of water (0.7 mL), 15% NaOH (0.7 mL), and water (2.1 mL). After stirring for an additional 2 h, the suspension was filtered, and the filtrate was washed with additional THF (100 mL). The combined organic solution was concentrated in vacuo, and the resulting residue was chromatographed on silica gel (40% ethyl acetate in hexanes) to afford **13a** (1.77 g, 8.17 mmol, 94%) as a white solid; mp 61°C. ¹H NMR (CDCl₃) δ: 1.01–1.06 (2H, m), 1.41 (1H, bs), 1.46–1.57 (1H, m), 1.87–1.93 (1H, m), 3.66 (2H, d, *J* = 6.6 Hz), 7.17 (2H, d, *J* = 8.4 Hz), 7.52 (2H, d, *J* = 8.4 Hz). ¹³C NMR (CDCl₃) δ: 14.3, 21.1, 25.9, 66.0, 124.3 (q, *J*_{C-F} = 269.2 Hz), 125.2 (2C, q, *J*_{C-F} = 3.5 Hz), 125.9 (2C), 127.8 (q, *J*_{C-F} = 33.1 Hz), 146.9. HRMS calcd. for C₁₁H₁₁F₃O: 216.0762; found: 216.0759.

***trans*-2-(3-(Trifluoromethyl)phenyl)cyclopropylmethanol (13b)** was prepared by procedure D, using **10b** (0.95 g, 4.13 mmol) and LiAlH₄ (0.30 g, 7.91 mmol), in 87% yield (0.78 g, 3.61 mmol). ¹H NMR (CDCl₃) δ: 0.96 (2H, dd, *J*₁ = 7.5 Hz, *J*₂ = 6.9 Hz), 1.37–1.48 (1H, m), 1.85 (1H, dt, *J*₁ = 6.9 Hz, *J*₂ = 4.2 Hz), 2.96 (1H, bs), 3.54 (1H, dd, *J*₁ = 11.4 Hz, *J*₂ = 6.3 Hz), 3.63 (1H, dd, *J*₁ = 11.4 Hz, *J*₂ = 6.3 Hz), 7.19–7.41 (4H, m). ¹³C NMR (CDCl₃) δ: 13.9, 21.1, 25.4, 65.9, 122.3 (q, *J*_{C-F} = 3.3 Hz), 122.2 (q, *J*_{C-F} = 3.3 Hz), 124.2 (q, *J*_{C-F} = 270.2 Hz), 128.7, 129.1, 130.5 (q, *J*_{C-F} = 32.0 Hz), 143.7. HRMS calcd. for C₁₁H₁₁F₃O: 216.0762; found: 216.0766.

***trans*-2-(4-Fluorophenyl)cyclopropylmethanol (13c)** was prepared by procedure D, using **10c** (1.95 g, 10.8 mmol) and LiAlH₄ (1.00 g, 26.4 mmol), in 91% yield (1.63 g, 9.81 mmol). ¹H NMR (CDCl₃) δ: 0.86–0.93 (2H, m), 1.30–1.41 (1H, m), 1.78 (1H, ddd, *J*₁ = 8.4 Hz, *J*₂ = 6.0 Hz, *J*₃ = 4.5 Hz), 2.45–2.51 (1H, m), 3.57 (2H, d, *J* = 6.9 Hz), 6.89–7.04 (4H, m). ¹³C NMR (CDCl₃) δ: 13.5, 20.6, 25.0, 66.2, 115.0 (2C, d, *J*_{C-F} = 20.9 Hz), 127.3 (2C, d, *J*_{C-F} = 7.7 Hz), 138.0 (d, *J*_{C-F} = 2.2 Hz), 161.1 (d, *J*_{C-F} = 241.5 Hz). HRMS calcd. for C₁₀H₁₁FO: 166.0794; found: 166.0796.

***trans*-2-(3-Fluorophenyl)cyclopropylmethanol (13d)** was prepared by procedure D, using **10d** (1.00 g, 5.55 mmol) and LiAlH₄ (0.50 g, 13.2 mmol), in 87% yield (0.80 g, 4.83 mmol). ¹H NMR (CDCl₃) δ: 0.92 (2H, t, *J* = 7.2 Hz), 1.34–1.44 (1H, m), 1.76–1.82 (1H, m), 3.30 (1H, s), 3.50–3.61 (2H, m), 6.75 (1H, dt, *J*₁ = 8.1 Hz, *J*₂ = 2.4 Hz), 6.80–6.87 (2H, m), 7.18 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 6.0 Hz). ¹³C NMR (CDCl₃) δ: 14.0, 21.1, 25.4, 65.8, 112.4 (d, *J*_{C-F} = 20.9 Hz), 112.5 (d, *J*_{C-F} = 20.9 Hz), 121.6 (d, *J*_{C-F} = 2.3 Hz), 129.7 (d, *J*_{C-F} = 8.8 Hz), 145.5 (d, *J*_{C-F} = 7.7 Hz), 163.0 (d, *J*_{C-F} = 243.8 Hz). HRMS calcd. for C₁₀H₁₁FO: 166.0794; found: 166.0796.

***trans*-2-(4-Methylphenyl)cyclopropylmethanol (13e)** was prepared by procedure D, using **10e** (2.00 g, 11.3 mmol) and LiAlH₄ (1.00 g, 26.4 mmol), in 92% yield (1.68 g, 10.4 mmol). ¹H NMR (CDCl₃) δ: 0.88–0.97 (2H, m), 1.37–1.48 (1H, m), 1.80 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz), 2.12 (1H, s), 2.34 (3H, s), 3.55–3.66 (2H, m), 6.99 (2H, d, *J* = 7.8 Hz), 7.10 (2H, d, *J* = 7.8 Hz). ¹³C NMR (CDCl₃) δ: 13.6, 21.0 (2C), 25.0, 66.5, 125.8 (2C), 129.0 (2C), 135.1, 139.4. HRMS calcd. for C₁₁H₁₄O: 162.1045; found: 162.1041.

***trans*-2-(3-Methylphenyl)cyclopropylmethanol (13f)** was prepared by procedure D, using **10f** (2.00 g, 11.3 mmol) and LiAlH₄ (1.00 g, 26.4 mmol), in 97% yield (1.79 g, 11.0 mmol). ¹H NMR (CDCl₃) δ: 0.92–1.03 (2H, m), 1.42–1.53 (1H, m), 1.83 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.1 Hz), 2.39 (3H, s), 2.82 (1H, s), 3.57–3.68 (2H, m), 6.92–7.24 (4H, m). ¹³C NMR (CDCl₃) δ: 13.8, 21.3, 21.5, 25.1, 66.3, 122.9, 126.4, 126.7, 128.3, 137.9, 142.6. HRMS calcd. for C₁₁H₁₄O: 162.1045; found: 162.1042.

***trans*-2-(4-Methoxyphenyl)cyclopropylmethanol (13g)** was prepared by procedure D, using **10g** (0.56 g, 2.88 mmol) and LiAlH₄ (0.25 g, 6.59 mmol), in 95% yield (0.49 g, 2.75 mmol). ¹H NMR (CDCl₃) δ: 0.84–0.93 (2H, m), 1.33–1.46 (1H, m), 1.44 (1H, s), 1.78 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 4.8 Hz), 3.54–3.65 (2H, m), 3.78 (3H, s), 6.81 (2H, dt, *J*₁ = 8.4 Hz, *J*₂ = 2.1 Hz), 7.01 (2H, dt, *J*₁ = 8.7 Hz, *J*₂ = 2.4 Hz). ¹³C NMR (CDCl₃) δ: 13.3, 20.6, 24.7, 55.3, 66.6, 113.8 (2C), 127.0 (2C), 134.4, 157.7. HRMS calcd. for C₁₁H₁₄O₂: 178.0994; found: 178.0990.

***trans*-2-(3-Methoxyphenyl)cyclopropylmethanol (13h)** was prepared by procedure D, using **10h** (1.16 g, 6.34 mmol) and LiAlH₄ (0.50 g, 13.2 mmol), in 78% yield (0.88 g, 4.94 mmol). ¹H NMR (CDCl₃) δ: 0.90–1.00 (2H, m), 1.41–1.51 (1H, m), 1.43 (1H, s), 1.81 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 4.8 Hz), 3.55–3.68 (2H, m), 3.79 (3H, s), 6.61–6.72 (3H, m), 7.18 (1H, t, *J* = 7.8 Hz). ¹³C NMR (CDCl₃) δ: 13.9, 21.3,

25.3, 55.1, 66.2, 110.8, 111.8, 118.2, 129.3, 144.4, 160.0. HRMS calcd. for $C_{11}H_{14}O_2$: 178.0994; found: 178.1001.

Methyl (*trans*-2-(4-(trifluoromethyl)phenyl)cyclopropyl)acetate (11a). Procedure E

A solution of **10a** (1.69 g, 7.34 mmol) and DMF (2 drops) in benzene (50 mL) under a nitrogen atmosphere was cooled with a water bath as oxalyl chloride (1.3 mL, 14.9 mmol) was added. The reaction mixture was stirred for 2 h, and volatiles were removed in vacuo. The crude carbonyl chloride was dissolved in CH_2Cl_2 (25 mL), and the resulting mixture was added slowly to a solution of CH_2N_2 in ether, prepared from Diazald® (10 g, 46.7 mmol). The reaction mixture was stirred at room temperature for 16 h and then concentrated in vacuo. The resulting diazoketone was chromatographed on silica gel (20% ethyl acetate in hexanes).

The diazoketone was dissolved in dioxane (30 mL), and the solution was added portionwise to a suspension of Ag_2O (3.00 g, 12.9 mmol) and $Na_2S_2O_3$ (2.04 g, 12.9 mmol) in water (100 mL) at 75°C. The resulting suspension was stirred for 2 h and then cooled to room temperature and filtered through Celite®. The filtrate was made basic (NaOH) and washed with ether (2 × 100 mL). The aqueous layer was acidified (concentrated HCl) and extracted with ether (2 × 100 mL). The combined organic layer was washed with brine (100 mL), dried over $MgSO_4$, filtered, and concentrated in vacuo.

The resulting acid was dissolved in CH_2Cl_2 (25 mL) and added slowly to a solution of CH_2N_2 in ether, prepared from Diazald® (10 g, 46.7 mmol). The mixture was stirred at room temperature for 16 h and then concentrated in vacuo. The crude product was purified by radial chromatography (10% ethyl acetate in hexanes) to afford **11a** (1.04 g, 4.04 mmol, 55% combined yield) as a clear, colorless oil. 1H NMR ($CDCl_3$) δ : 0.94 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.4$ Hz), 1.05 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.4$ Hz), 1.37–1.48 (1H, m), 1.81 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.42 (2H, d, $J = 7.2$ Hz), 3.70 (3H, s), 7.17 (2H, d, $J = 8.1$ Hz), 7.49 (2H, d, $J = 8.1$ Hz). ^{13}C NMR ($CDCl_3$) δ : 15.8, 19.1, 22.8, 38.5, 51.6, 124.3 (q, $J_{C-F} = 270.3$ Hz), 125.1 (2C, q, $J_{C-F} = 3.4$ Hz), 126.1 (2C), 127.8 (q, $J_{C-F} = 33.1$ Hz), 146.8, 172.8. HRMS calcd. for $C_{13}H_{13}F_3O_2$: 258.0868; found: 258.0871.

Methyl (*trans*-2-(3-(trifluoromethyl)phenyl)cyclopropyl)acetate (11b) was prepared by procedure E, using **10b** (1.71 g, 7.43 mmol), oxalyl chloride (1.3 mL, 14.9 mmol), and Ag_2O (3.00 g, 12.9 mmol), in 51% yield (0.98 g, 3.79 mmol). 1H NMR ($CDCl_3$) δ : 0.90 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 1.10 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 1.33–1.44 (1H, m), 1.79 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.8$ Hz), 2.39 (2H, d, $J = 6.9$ Hz), 3.67 (3H, s), 7.22–7.44 (4H, m). ^{13}C NMR ($CDCl_3$) δ : 15.3, 18.7, 22.6, 38.4, 51.5, 122.3 (q, $J_{C-F} = 3.3$ Hz), 122.7 (q, $J_{C-F} = 3.3$ Hz), 124.2 (q, $J_{C-F} = 270.8$ Hz), 128.6, 129.4, 130.5 (q, $J_{C-F} = 32.0$ Hz), 143.6, 172.7. HRMS calcd. for $C_{13}H_{13}F_3O_2$: 258.0868; found: 258.0868.

Methyl (*trans*-2-(4-fluorophenyl)cyclopropyl)acetate (11c) was prepared by procedure E, using **10c** (1.38 g, 7.66 mmol), oxalyl chloride (1.3 mL, 14.9 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 40% yield (0.64 g, 3.07 mmol). 1H NMR ($CDCl_3$) δ : 0.79–0.86 (1H, m), 0.90–0.97 (1H, m),

1.26–1.37 (1H, m), 1.70–1.76 (1H, m), 2.39 (2H, dd, $J_1 = 6.9$ Hz, $J_2 = 2.4$ Hz), 3.69 (3H, s), 6.85–7.10 (4H, m). ^{13}C NMR ($CDCl_3$) δ : 14.9, 18.1, 22.2, 38.6, 51.6, 114.9 (2C, d, $J_{C-F} = 21.0$ Hz), 127.5 (2C, d, $J_{C-F} = 7.7$ Hz), 138.1, 161.1 (d, $J_{C-F} = 242.7$ Hz), 173.0. HRMS calcd. for $C_{12}H_{13}FO_2$: 208.0900; found: 208.0905.

Methyl (*trans*-2-(3-fluorophenyl)cyclopropyl)acetate (11d) was prepared by procedure E, using **10d** (1.33 g, 7.38 mmol), oxalyl chloride (1.3 mL, 14.9 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 57% yield (0.87 g, 4.18 mmol). 1H NMR ($CDCl_3$) δ : 0.87 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.1$ Hz), 0.98 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.4$ Hz), 1.30–1.41 (1H, m), 1.73 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 2.31–2.45 (2H, m), 3.67 (3H, s), 6.73–6.87 (3H, m), 7.17 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 6.6$ Hz). ^{13}C NMR ($CDCl_3$) δ : 15.5, 18.7, 22.6, 38.5, 51.6, 112.3 (d, $J_{C-F} = 21.0$ Hz), 112.8 (d, $J_{C-F} = 21.0$ Hz), 121.7 (d, $J_{C-F} = 2.3$ Hz), 129.6 (d, $J_{C-F} = 8.9$ Hz), 145.3 (d, $J_{C-F} = 7.7$ Hz), 162.9 (d, $J_{C-F} = 242.7$ Hz), 172.8. HRMS calcd. for $C_{12}H_{13}FO_2$: 208.0900; found: 208.0896.

Methyl (*trans*-2-(4-methylphenyl)cyclopropyl)acetate (11e) was prepared by procedure E, using **10e** (1.34 g, 7.60 mmol), oxalyl chloride (1.3 mL, 14.9 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 48% yield (0.75 g, 3.67 mmol). 1H NMR ($CDCl_3$) δ : 0.87 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.1$ Hz), 1.02 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 5.1$ Hz), 1.34–1.45 (1H, m), 1.78 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.8$ Hz), 2.34–2.53 (2H, m), 2.35 (3H, s), 3.74 (3H, s), 7.03 (2H, d, $J = 7.8$ Hz), 7.11 (2H, d, $J = 7.8$ Hz). ^{13}C NMR ($CDCl_3$) δ : 15.1, 18.2, 21.0, 22.6, 38.8, 51.6, 126.0 (2C), 129.0 (2C), 135.1, 139.4, 172.1. HRMS calcd. for $C_{13}H_{16}O_2$: 204.1150; found: 204.1146.

Methyl (*trans*-2-(3-methylphenyl)cyclopropyl)acetate (11f) was prepared by procedure E, using **10f** (1.33 g, 7.55 mmol), oxalyl chloride (1.3 mL, 14.9 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 46% yield (0.71 g, 3.48 mmol). 1H NMR ($CDCl_3$) δ : 0.87 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 1.02 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.4$ Hz), 1.36–1.47 (1H, m), 1.75 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.32–2.53 (2H, m), 2.34 (3H, s), 3.72 (3H, s), 6.90–7.19 (4H, m). ^{13}C NMR ($CDCl_3$) δ : 15.4, 18.4, 21.4, 22.8, 38.8, 41.6, 123.0, 126.4, 126.7, 128.2, 137.8, 142.5, 172.1. HRMS calcd. for $C_{13}H_{16}O_2$: 204.1150; found: 204.1146.

Methyl (*trans*-2-(4-methoxyphenyl)cyclopropyl)acetate (11g) was prepared by procedure E, using **10g** (1.26 g, 6.56 mmol), oxalyl chloride (1.5 mL, 17.2 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 42% yield (0.62 g, 2.82 mmol). 1H NMR ($CDCl_3$) δ : 0.80 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 0.93 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 5.1$ Hz), 1.24–1.36 (1H, m), 1.72 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.8$ Hz), 2.32–2.47 (2H, m), 3.70 (3H, s), 3.77 (3H, s), 6.80 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 3.3$ Hz), 7.07 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 3.3$ Hz). ^{13}C NMR ($CDCl_3$) δ : 14.7, 17.8, 22.1, 38.8, 51.6, 55.3, 113.7 (2C), 127.2 (2C), 134.5, 157.7, 173.2. HRMS calcd. for $C_{13}H_{16}O_3$: 220.1099; found: 220.1105.

Methyl (*trans*-2-(3-methoxyphenyl)cyclopropyl)acetate (11h) was prepared by procedure E, using **10h** (1.25 g, 6.50 mmol), oxalyl chloride (1.5 mL, 17.2 mmol), and Ag_2O (2.50 g, 10.8 mmol), in 49% yield (0.70 g, 3.19 mmol). 1H NMR ($CDCl_3$) δ : 0.87 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz),

1.01 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 1.35–1.45 (1H, m), 1.75 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.31–2.50 (2H, m), 3.70 (3H, s), 3.78 (3H, s), 6.65–6.73 (3H, m), 7.17 (1H, t, $J = 7.5$ Hz). ^{13}C NMR (CDCl_3) δ : 15.4, 18.5, 22.9, 38.7, 51.6, 55.0, 110.9, 111.8, 118.4, 129.2, 144.3, 159.7, 173.0. HRMS calcd. for $\text{C}_{13}\text{H}_{16}\text{O}_3$: 220.1099; found: 220.1104.

(*trans*-2-((4-Trifluoromethyl)phenyl)cyclopropyl)acetic acid (12a). Procedure F

A solution of **11a** (0.75 g, 2.90 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.90 g, 21.9 mmol) in methanol (35 mL) was stirred at room temperature for 6 h. This was concentrated in vacuo, and the residue was dissolved in water (75 mL). This was then acidified (concentrated HCl) and extracted with CH_2Cl_2 (3×30 mL). The combined organic layer was washed with brine (50 mL), dried over Na_2SO_4 , filtered, and concentrated in vacuo to afford **12a** (0.69 g, 2.83 mmol, 98%) as a white solid; mp 79–80°C. ^1H NMR (CDCl_3) δ : 0.98 (1H, dt, $J_1 = 10.8$ Hz, $J_2 = 5.4$ Hz), 1.08 (1H, dt, $J_1 = 10.8$ Hz, $J_2 = 5.4$ Hz), 1.39–1.49 (1H, m), 1.84 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.8$ Hz), 2.48 (2H, d, $J = 7.2$ Hz), 7.18 (2H, d, $J = 8.1$ Hz), 7.51 (2H, d, $J = 8.1$ Hz), 11.21 (1H, bs). ^{13}C NMR (CDCl_3) δ : 15.7, 18.6, 22.8, 38.5, 124.3 (q, $J_{\text{C-F}} = 269.1$ Hz), 125.2 (2C, q, $J_{\text{C-F}} = 3.3$ Hz), 126.2 (2C), 128.0 (q, $J_{\text{C-F}} = 32.0$ Hz), 146.6, 178.9. HRMS calcd. for $\text{C}_{12}\text{H}_{11}\text{F}_3\text{O}_2$: 244.0711; found: 244.0706.

(*trans*-2-((3-Trifluoromethyl)phenyl)cyclopropyl)acetic acid (12b) was prepared by procedure F, using **11b** (0.70 g, 2.71 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.90 g, 21.9 mmol), in 97% yield (0.64 g, 2.63 mmol). ^1H NMR (CDCl_3) δ : 0.97 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.7$ Hz), 1.08 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.7$ Hz), 1.39–1.50 (1H, m), 1.86 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 2.49 (2H, d, $J = 7.2$ Hz), 7.27–7.51 (4H, m), 11.88 (1H, bs). ^{13}C NMR (CDCl_3) δ : 15.4, 18.3, 22.7, 38.5, 122.5 (q, $J_{\text{C-F}} = 3.3$ Hz), 122.8 (q, $J_{\text{C-F}} = 3.3$ Hz), 124.2 (q, $J_{\text{C-F}} = 270.8$ Hz), 128.7, 129.4, 130.6 (q, $J_{\text{C-F}} = 32.0$ Hz), 143.3, 179.3. HRMS calcd. for $\text{C}_{12}\text{H}_{11}\text{F}_3\text{O}_2$: 244.0711; found: 244.0705.

(*trans*-2-(4-Fluorophenyl)cyclopropyl)acetic acid (12c) was prepared by procedure F, using **11c** (0.57 g, 2.74 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.80 g, 19.1 mmol), in 90% yield (0.48 g, 2.47 mmol); mp 62–63°C. ^1H NMR (CDCl_3) δ : 0.89 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.1$ Hz), 1.00 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz), 1.31–1.42 (1H, m), 1.80 (1H, dt, $J_1 = 9.6$ Hz, $J_2 = 5.4$ Hz), 2.47 (2H, d, $J = 7.2$ Hz), 6.93–7.01 (2H, m), 7.06–7.12 (2H, m), 11.98 (1H, s). ^{13}C NMR (CDCl_3) δ : 14.9, 17.8, 22.2, 38.7, 115.0 (2C, d, $J_{\text{C-F}} = 21.0$ Hz), 127.7 (2C, d, $J_{\text{C-F}} = 7.7$ Hz), 137.9 (d, $J_{\text{C-F}} = 2.2$ Hz), 161.2 (d, $J_{\text{C-F}} = 241.6$ Hz), 179.6. HRMS calcd. for $\text{C}_{11}\text{H}_{11}\text{FO}_2$: 194.0743; found: 194.0750.

(*trans*-2-(3-Fluorophenyl)cyclopropyl)acetic acid (12d) was prepared by procedure F, using **11d** (0.73 g, 3.51 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.70 g, 16.7 mmol), in 92% yield (0.63 g, 3.24 mmol). ^1H NMR (CDCl_3) δ : 0.96 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.4$ Hz), 1.06 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz), 1.39–1.50 (1H, m), 1.82 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.42–2.56 (2H, m), 6.82–6.94 (3H, m), 7.25 (1H, dt, $J_1 = 7.8$ Hz, $J_2 = 6.0$ Hz), 12.13 (1H, s). ^{13}C NMR (CDCl_3) δ : 15.5, 18.4, 22.7, 38.6, 112.5 (d, $J_{\text{C-F}} = 20.9$ Hz), 112.8 (d, $J_{\text{C-F}} =$

22.1 Hz), 121.8 (d, $J_{\text{C-F}} = 2.2$ Hz), 129.7 (d, $J_{\text{C-F}} = 8.8$ Hz), 145.2 (d, $J_{\text{C-F}} = 7.7$ Hz), 163.0 (d, $J_{\text{C-F}} = 243.8$ Hz), 179.6. HRMS calcd. for $\text{C}_{11}\text{H}_{11}\text{FO}_2$: 194.0743; found: 194.0736.

(*trans*-2-(4-Methylphenyl)cyclopropyl)acetic acid (12e) was prepared by procedure F, using **11e** (0.69 g, 3.38 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.70 g, 16.7 mmol), in 84% yield (0.54 g, 2.84 mmol); mp 62–63°C. ^1H NMR (CDCl_3) δ : 0.93 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.1$ Hz), 1.07 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 1.39–1.50 (1H, m), 1.83 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.39 (3H, s), 2.42–2.60 (2H, m), 7.08 (2H, d, $J = 8.1$ Hz), 7.15 (2H, d, $J = 8.1$ Hz), 12.00 (1H, s). ^{13}C NMR (CDCl_3) δ : 15.1, 17.9, 21.0, 22.6, 38.9, 126.0 (2C), 129.1 (2C), 135.2, 139.3, 179.7. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{O}_2$: 190.0994; found: 190.0992.

(*trans*-2-(3-Methylphenyl)cyclopropyl)acetic acid (12f) was prepared by procedure F, using **11f** (0.55 g, 2.69 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.60 g, 14.3 mmol), in 94% yield (0.48 g, 2.52 mmol). ^1H NMR (CDCl_3) δ : 1.00 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.1$ Hz), 1.16 (1H, dt, $J_1 = 8.1$ Hz, $J_2 = 5.4$ Hz), 1.49–1.60 (1H, m), 1.89 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 5.1$ Hz), 2.47 (3H, s), 2.47–2.67 (2H, m), 7.03–7.35 (4H, m), 12.17 (1H, s). ^{13}C NMR (CDCl_3) δ : 15.5, 18.1, 21.5, 22.9, 38.9, 123.2, 126.6, 126.9, 128.4, 137.9, 142.4, 179.8. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{O}_2$: 190.0994; found: 190.0990.

(*trans*-2-(4-Methoxyphenyl)cyclopropyl)acetic acid (12g) was prepared by procedure F, using **11g** (0.50 g, 2.27 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.60 g, 14.3 mmol), in 98% yield (0.46 g, 2.22 mmol); mp 74–75°C. ^1H NMR (CDCl_3) δ : 0.82 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.1$ Hz), 0.95 (1H, dt, $J_1 = 8.7$ Hz, $J_2 = 5.7$ Hz), 1.27–1.37 (1H, m), 1.75 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 4.8$ Hz), 2.36–2.52 (2H, m), 3.78 (3H, s), 6.80 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 3.0$ Hz), 7.04 (2H, dt, $J_1 = 8.7$ Hz, $J_2 = 3.0$ Hz), 10.09 (1H, bs). ^{13}C NMR (CDCl_3) δ : 14.6, 17.5, 22.1, 38.7, 55.3, 113.8 (2C), 127.2 (2C), 134.3, 157.8, 179.3. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{O}_3$: 206.0943; found: 206.0938.

(*trans*-2-(3-Methoxyphenyl)cyclopropyl)acetic acid (12h) was prepared by procedure F, using **11h** (0.52 g, 2.36 mmol) and $\text{LiOH}\cdot\text{H}_2\text{O}$ (0.60 g, 14.3 mmol), in 98% yield (0.48 g, 2.31 mmol). ^1H NMR (CDCl_3) δ : 0.90 (1H, dt, $J_1 = 9.0$ Hz, $J_2 = 5.7$ Hz), 1.05 (1H, dt, $J_1 = 8.4$ Hz, $J_2 = 5.1$ Hz), 1.37–1.48 (1H, m), 1.79 (1H, dt, $J_1 = 9.3$ Hz, $J_2 = 4.8$ Hz), 2.37–2.56 (2H, m), 3.81 (3H, s), 6.67–6.75 (3H, m), 7.20 (1H, t, $J = 7.8$ Hz), 11.68 (1H, bs). ^{13}C NMR (CDCl_3) δ : 15.3, 18.1, 23.0, 38.7, 55.1, 111.1, 111.9, 118.4, 129.3, 144.1, 159.7, 179.4. HRMS calcd. for $\text{C}_{12}\text{H}_{14}\text{O}_3$: 206.0943; found: 206.0940.

1-[[[(*trans*-2-(4-(Trifluoromethyl)phenyl)cyclopropyl)-methyl]carbonyl]oxy]-2(1H)-pyridinethione (2a)

PTOC esters were generally prepared by either the standard method (15) or the mild method (29). To a solution of acid **12a** (0.50 g, 2.05 mmol) in dry benzene at 0°C under nitrogen was added dropwise oxalyl chloride (0.45 mL, 5.1 mmol) via syringe transfer followed by one drop of DMF. The reaction mixture was stirred for 3 h at room temperature until gas evolution ceased. The excess oxalyl chloride and benzene were removed under reduced pressure. The resulting acid chloride was dissolved in dry benzene (5 mL)

and transferred by cannula into a light-shielded flask in an ice bath containing a suspension of *N*-hydroxypyridine-2-thione sodium salt (0.37 g, 2.46 mmol) and a catalytic amount of DMAP (12.2 mg, 0.1 mmol) in 10 mL of benzene. The mixture was allowed to warm to room temperature with stirring and was maintained at room temperature for 3 h. The mixture was diluted with ether (10 mL) and washed with saturated NaHCO₃ solution (5 mL) and saturated NaCl solution (10 mL). The organic layer was dried over MgSO₄ and concentrated to give crude PTOC ester **2a**, which was purified by column chromatography on silica gel (hexanes–EtOAc = 1:1, v/v) to yield 0.56 g (1.59 mmol, 78%). ¹H NMR (CDCl₃) δ: 1.08 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 6.0 Hz), 1.15 (1H, dt, *J*₁ = 8.5 Hz, *J*₂ = 5.5 Hz), 1.51–1.57 (1H, m), 1.99 (1H, dt, *J*₁ = 9.5 Hz, *J*₂ = 5.0 Hz), 2.76–2.92 (2H, m), 6.62 (1H, dt, *J*₁ = 7.5 Hz, *J*₂ = 2.0 Hz), 7.17–7.21 (3H, m), 7.47 (2H, d, *J* = 8.0 Hz), 7.57 (1H, d, *J* = 7.0 Hz), 7.66 (1H, dd, *J*₁ = 8.5 Hz, *J*₂ = 1.5 Hz). ¹³C NMR (CDCl₃) δ: 15.6, 18.0, 22.8, 36.1, 112.7, 124.2 (q, *J*_{C-F} = 270.5 Hz), 125.1 (2C, q, *J*_{C-F} = 3.6 Hz), 126.2 (2C), 127.9 (q, *J*_{C-F} = 32.3 Hz), 133.6, 137.2, 137.5, 146.1, 167.9, 175.5.

1-[[[(*trans*-2-(3-(Trifluoromethyl)phenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2b**)]**

To a solution of acid **12b** (146 mg, 0.60 mmol) and 2,2'-dipyridyl disulfide bis-*N*-oxide (1.1 equiv., 166 mg, 0.66 mmol) in dry CH₂Cl₂ (10 mL) in a flame-dried flask wrapped with aluminum foil was added Ph₃P (1.1 equiv., 172 mg, 0.66 mmol) at room temperature under nitrogen. The reaction mixture was stirred for 1 h and then treated with 5 mL of 10% aqueous Na₂CO₃ solution. The organic layer was separated, and the aqueous layer was extracted with 10 mL of CH₂Cl₂. The combined organic extracts were washed with saturated NaCl solution (10 mL), dried over MgSO₄, and concentrated under reduced pressure. Column chromatography of the residue on silica gel (hexanes–EtOAc = 1:1, v/v) under subdued light gave PTOC-ester **2b** (177 mg, 0.48 mmol, 80%). ¹H NMR (CDCl₃) δ: 1.09 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.5 Hz), 1.17 (1H, dt, *J*₁ = 8.5 Hz, *J*₂ = 5.5 Hz), 1.52–1.58 (1H, m), 2.01 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.0 Hz), 2.80–2.92 (2H, m), 6.64 (1H, dt, *J*₁ = 6.5 Hz, *J*₂ = 1.5 Hz), 7.20–7.23 (1H, m), 7.31–7.42 (4H, m), 7.58 (1H, d, *J* = 7.0 Hz), 7.69 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 1.5 Hz). ¹³C NMR (CDCl₃) δ: 15.3, 17.6, 22.8, 36.2, 112.6, 122.6 (q, *J*_{C-F} = 3.8 Hz), 122.9 (q, *J*_{C-F} = 3.6 Hz), 124.1 (q, *J*_{C-F} = 271.4 Hz), 128.8, 129.7, 130.6 (q, *J*_{C-F} = 32.3 Hz), 133.6, 137.3, 137.5, 142.8, 168.0, 175.7.

1-[[[(*trans*-2-(4-Fluorophenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2c**)]**

To a solution of acid **12c** (258 mg, 1.33 mmol) and 2,2'-dipyridyl disulfide bis-*N*-oxide (1.1 equiv., 369 mg, 1.46 mmol) in dry CH₂Cl₂ (10 mL) in a flame-dried flask wrapped with aluminum foil was added *n*-Bu₃P (1.1 equiv., 361 μL, 1.46 mmol) at 0°C under nitrogen. After 2 min, the ice bath was removed. The reaction mixture was stirred for 40 min before 10% aqueous Na₂CO₃ (10 mL) was added. The organic layer was separated and the aqueous layer was extracted with 10 mL of CH₂Cl₂. The combined organic extracts were washed with saturated NaCl solution (10 mL), dried over MgSO₄, and concentrated under reduced pressure.

Column chromatography on silica gel (hexanes–EtOAc = 1:1, v/v) under subdued light gave PTOC-ester **2c** (225 mg, 0.74 mmol, 56%). ¹H NMR (CDCl₃) δ: 0.99 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz), 1.05 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz), 1.39–1.50 (1H, m), 1.91 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.1 Hz), 2.72–2.90 (2H, m), 6.62 (1H, dt, *J*₁ = 7.2 Hz, *J*₂ = 1.8 Hz), 6.90–6.96 (2H, m), 7.05–7.11 (2H, m), 7.17–7.22 (1H, m), 7.57 (1H, dd, *J*₁ = 7.2 Hz, *J*₂ = 1.8 Hz), 7.67 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 1.8 Hz). ¹³C NMR (CDCl₃) δ: 14.7, 17.1, 22.3, 36.2, 112.5, 115.0 (2C, d, *J*_{C-F} = 21.0 Hz), 127.7 (2C, d, *J*_{C-F} = 7.7 Hz), 133.5, 137.3, 137.5 (d, *J*_{C-F} = 2.2 Hz), 137.6, 161.2 (d, *J*_{C-F} = 241.5 Hz), 168.2, 175.7.

1-[[[(*trans*-2-(3-Fluorophenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2d**)]** was prepared by the procedure of **2c**, using acid **12d** (250 mg, 1.29 mmol), 2,2'-dipyridyl disulfide bis-*N*-oxide (358 mg, 1.42 mmol), and *n*-Bu₃P (350 μL, 1.42 mmol), in 70% yield (272 mg, 0.90 mmol). ¹H NMR (CDCl₃) δ: 1.03 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.4 Hz), 1.11 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.4 Hz), 1.45–1.56 (1H, m), 1.93 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.1 Hz), 2.75–2.90 (2H, m), 6.63 (1H, dt, *J*₁ = 7.2 Hz, *J*₂ = 1.8 Hz), 6.70–6.92 (3H, m), 7.16–7.24 (2H, m), 7.57 (1H, dd, *J*₁ = 6.9 Hz, *J*₂ = 1.5 Hz), 7.68 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 1.8 Hz). ¹³C NMR (CDCl₃) δ: 15.2, 17.5, 22.7, 36.0, 112.5 (d, *J*_{C-F} = 21.0 Hz), 112.6, 112.8 (d, *J*_{C-F} = 22.1 Hz), 121.8 (d, *J*_{C-F} = 3.3 Hz), 129.6 (d, *J*_{C-F} = 8.8 Hz), 133.5, 137.0, 137.5, 144.5 (d, *J*_{C-F} = 6.6 Hz), 162.8 (d, *J*_{C-F} = 243.8 Hz), 167.9, 175.4.

1-[[[(*trans*-2-(4-Methylphenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2e**)]** was prepared by the procedure of **2c**, using acid **12e** (250 mg, 1.31 mmol), 2,2'-dipyridyl disulfide bis-*N*-oxide (364 mg, 1.45 mmol), and *n*-Bu₃P (358 μL, 1.45 mmol), in 76% yield (300 mg, 1.00 mmol). ¹H NMR (CDCl₃) δ: 0.98 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.7 Hz), 1.07 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.1 Hz), 1.42–1.51 (1H, m), 1.89 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.1 Hz), 2.30 (3H, s), 2.81 (2H, d, *J* = 6.9 Hz), 6.60 (1H, dt, *J*₁ = 6.9 Hz, *J*₂ = 1.5 Hz), 7.00–7.08 (4H, m), 7.15–7.21 (1H, m), 7.57 (1H, dd, *J*₁ = 7.2 Hz, *J*₂ = 1.5 Hz), 7.66 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 2.1 Hz). ¹³C NMR (CDCl₃) δ: 14.9, 17.0, 20.8, 22.6, 36.3, 112.5, 126.0 (2C), 128.9 (2C), 133.4, 135.2, 137.1, 137.6, 138.6, 168.0, 175.6.

1-[[[(*trans*-2-(3-Methylphenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2f**)]** was prepared by the procedure of **2c**, using acid **12f** (250 mg, 1.31 mmol), 2,2'-dipyridyl disulfide bis-*N*-oxide (364 mg, 1.45 mmol), and *n*-Bu₃P (358 μL, 1.45 mmol), in 82% yield (320 mg, 1.07 mmol). ¹H NMR (CDCl₃) δ: 0.99 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.1 Hz), 1.10 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.1 Hz), 1.47–1.55 (1H, m), 1.89 (1H, dt, *J*₁ = 8.7 Hz, *J*₂ = 5.1 Hz), 2.31 (3H, s), 2.74–2.90 (2H, m), 6.62 (1H, dt, *J*₁ = 7.2 Hz, *J*₂ = 1.8 Hz), 6.91–6.99 (3H, m), 7.12–7.22 (2H, m), 7.56 (1H, d, *J* = 7.2 Hz), 7.68 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 1.5 Hz). ¹³C NMR (CDCl₃) δ: 15.2, 17.2, 21.3, 22.9, 36.4, 112.5, 123.1, 126.6, 126.8, 128.2, 133.5, 137.3, 137.6, 137.9, 141.7, 168.1, 175.7.

1-[[[(*trans*-2-(4-Methoxyphenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2g**)]** was prepared by the procedure of **2b**, using acid **12g** (200 mg, 0.97 mmol),

2,2'-dipyridyl disulfide bis-*N*-oxide (269 mg, 1.07 mmol), and Ph₃P (281 mg, 1.07 mmol), in 73% yield (222 mg, 0.705 mmol). ¹H NMR (CDCl₃) δ: 0.95 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.5 Hz), 1.04 (1H, dt, *J*₁ = 8.5 Hz, *J*₂ = 5.5 Hz), 1.41–1.46 (1H, m), 1.89 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.0 Hz), 2.77–2.86 (2H, m), 3.77 (3H, s), 6.63 (1H, dt, *J*₁ = 7.0 Hz, *J*₂ = 2.0 Hz), 6.80–6.81 (2H, m), 7.06–7.08 (2H, m), 7.19–7.22 (1H, m), 7.56 (1H, d, *J* = 7.0 Hz), 7.69 (1H, dd, *J*₁ = 9.0 Hz, *J*₂ = 1.5 Hz). ¹³C NMR (CDCl₃) δ: 14.6, 16.8, 22.3, 36.4, 55.3, 112.6, 113.7 (2C), 127.4 (2C), 133.5, 133.7, 137.3, 137.6, 157.8, 168.2, 175.7.

1-[[[(*trans*-2-(3-Methoxyphenyl)cyclopropyl)methyl]carbonyloxy]-2(1*H*)-pyridinethione (2h) was prepared by the procedure of **2c**, using acid **12h** (400 mg, 1.94 mmol), 2,2'-dipyridyl disulfide bis-*N*-oxide (538 mg, 2.13 mmol), and *n*-Bu₃P (531 μL, 2.13 mmol), in 78% yield (477 mg, 1.51 mmol). ¹H NMR (CDCl₃) δ: 0.98 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.1 Hz), 1.09 (1H, dt, *J*₁ = 8.4 Hz, *J*₂ = 5.4 Hz), 1.44–1.54 (1H, m), 1.89 (1H, dt, *J*₁ = 9.0 Hz, *J*₂ = 5.1 Hz), 2.80 (2H, d, *J* = 7.2 Hz), 3.76 (3H, s), 6.60 (1H, dt, *J*₁ = 6.6 Hz, *J*₂ = 1.8 Hz), 6.65–6.71 (3H, m), 7.13–7.20 (2H, m), 7.56 (1H, dd, *J*₁ = 7.2 Hz, *J*₂ = 1.5 Hz), 7.64 (1H, dd, *J*₁ = 7.2 Hz, *J*₂ = 1.5 Hz). ¹³C NMR (CDCl₃) δ: 15.1, 17.3, 23.0, 36.2, 55.0, 111.1, 111.9, 112.4, 118.4, 129.2, 133.5, 137.0, 137.6, 143.4, 159.5, 167.9, 175.5.

Indirect kinetic studies

These studies followed the method of Newcomb et al. as previously described (4, 17). Benzeneselenol, prepared by the method of Foster (30), was distilled under subdued light. Samples were divided into 1 mL portions and sealed under vacuum in ampoules that were stored at ca. –70°C. The amount of diphenyl diselenide contaminant (typically < 4%) in each sample of PhSeH was determined by GC prior to use. In a flame-dried tube shielded from light containing a small stir bar, a mixture of radical precursors (0.04–0.05 M), PhSeH (0.5–2.0 M), and a hydrocarbon standard (octane or dodecane) in freshly distilled THF was sparged with nitrogen. The tubes were equilibrated in a temperature-regulated bath for several minutes. The shields were removed, and the stirring mixture was irradiated with a 150 W tungsten filament lamp placed 0.4 m from the tube. After 40 min, the tubes were cooled at –78°C, and the contents were analyzed by GC. All yields reported for indirect kinetic experiments were calculated from response factors determined with authentic samples.

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