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Michael Addition of Stannyl Ketone Enolate to α,β-Unsaturated Esters Catalyzed by Tetrabutylammonium Bromide and an ab Initio Theoretical Study of the Reaction Course

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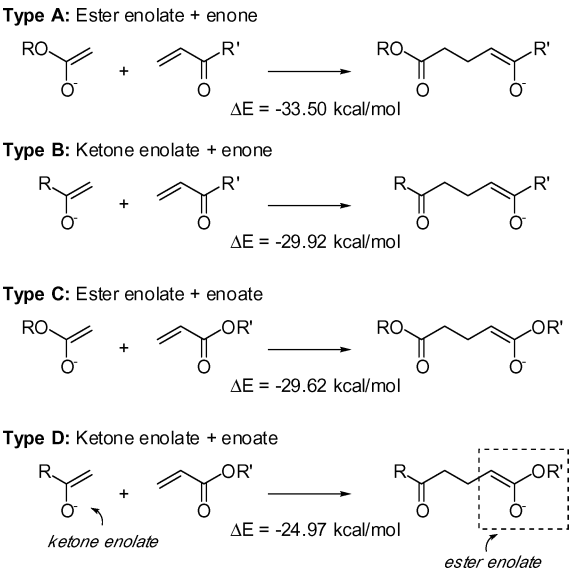
Abstract: Michael addition of stannyl ketone enolates to α,β-unsaturated esters was accomplished in the presence of a catalytic amount of tetrabutylammonium bromide (Bu_4NBr). Other typical systems using lithium enolate or silyl enolate with catalysts ($TiCl_4$ or Bu_4NF) failed to give the desired products. The bromide anion from Bu_4NBr coordinates to the tin center in enolate to accelerate the conjugate addition where a five-coordinated tin species was generated. The coordination of the bromide anion significantly raises the HOMO level of tin enolate and enhances its nucleophilicity. The conjugate addition provides the intermediate Michael adduct, which has an ester enolate moiety, and the adduct immediately transforms to α-stannyl γ-ketoester by keto−enol tautomerization. This step contributes to the stabilization of the product system and leads to a thermodynamically favorable reaction course. An ab initio calculation reveals that the activation energy in the reaction using the bromide anion is lower than that of the reaction without using it. The transition state in either reaction course has a linear structure, not a cyclic one. This system can be applied to a variety of tin enolates and α,β-unsaturated carbonyls involving enoates, enones, and unsaturated amides.

Introduction

Michael addition of metal enolates to α,β-unsaturated carbonyls has been widely studied and provides an important method for preparation of δ-dicarbonyl compounds under neutral and mild conditions.[1] Metal enolates derived from ketones and esters are typical as Michael donors, and α,β-unsaturated ketones and esters are often used as Michael acceptors. Therefore, there are four types of combinations between the donors and the acceptors as shown in reaction types A−D (Scheme 1). Although those reactions seem to be similar and often are considered to be in the same class of reaction, there is a significant difference among them. While thermal or catalytic reactions in types A−C have been much studied and reported,[2] the reaction of type D under thermal or catalytic conditions has hardly been reported except for a few examples.[3,4] We carried out a theoretical calculation of the energy difference Δ*E* between the product and the starting systems in types A−D and found that reaction type D is the most disfavorable (Scheme 1).[5] When

Scheme 1. Reaction Patterns between Enolates and α,β-Unsaturated Carbonyls (Energy Values Calculated when R = R′ = Me)



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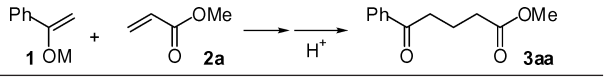
(1) *Comprehensive Organic Syntheses*; Trost, B. M., Ed.; Pergamon Press: Oxford, U.K., 1991; Vol. 4.
(2) Simple examples using lithium enolate under thermal conditions for types A−C: (a) Oare, D. A.; Heathcock, C. H. *J. Org. Chem.* **1990**, *55*, 157−172. (b) Yamaguchi, M.; Tsukamoto, M.; Hirao, I. *Chem. Lett.* **1984**, 375−376.
(3) The classical example using a strong base for the addition of cycloalkanone enolate to enoates. House, H. O.; Roelofs, W. L.; Trost, B. M. *J. Org. Chem.* **1966**, *31*, 646−655.

Table 1. Addition of Ketone Enolate to α,β-Unsaturated Ester[a]



entry	M	additive (mmol)	conditions	yield/%
1	Li		THF, −78 °C, 48 h	0
2	$SiMe_3$	$TiCl_4$ (1.0)	CH_2Cl_2, −78 °C, 15 min	81
3	$SiMe_3$	$TiCl_4$ (0.1)	CH_2Cl_2, −78 °C, 2 h	<10[b]
4	$SiMe_3$	Bu_4NF (0.1)	THF, 0 °C, 0.5 h	19[c]
5	$SiMe_3$	CeF (0.1)	THF, 63 °C, 6 h	<5
6	$SnBu_3$		THF, 63 °C, 12 h	0
7	$SnBu_3$	Bu_4NBr (0.1)	THF, 25 °C, 12 h	64

[a] Metal enolate **1** (3.0 equiv), methyl acrylate **2a** (1.0 equiv). [b] Less than 10% yield under conditions of either −78 °C, 15 min; 25 °C, 6 h; or 40 °C, 12 h. [c] Less than 20% yield under conditions of either −78 °C, 15 min; 25 °C, 6 h; or 63 °C, 6 h.

one considers the entropic factor, it is understood why only the reaction of type D could not proceed in thermal or catalytic conditions. Because ester enolates are generally more labile than ketone enolates, reaction type D including transformation from ketone enolate into ester enolate is not preferred in the thermodynamic point of view.[6] To complete the reaction, more than an equimolar amount of additives is generally required due to stabilization of the product system.[7] A few examples reported for the catalytic reaction of type D are ascribed to the fluorine-stabilized effect or stabilized by further transformation of the product system.[4,8] To design a catalytic or thermal system of type D, a number of groups have developed chemical synthons such ortho esters,[9] thioesters,[10] or a cationic species[11] as unsaturated ester equivalents, and β-lithiated enamines[12] as ketone enolate equivalents in place of the direct use of α,β-unsaturated esters and ketone enolates.

In this paper, we report the first example of the catalytic Michael addition of ketone enolate to α,β-unsaturated ester by using tin enolate with a catalytic amount of tetrabutylammonium bromide.[13,14]

Results and Discussion

Reaction of Ketone Enolate to α,β-Unsaturated Carbonyls. The reaction of metal enolates **1** derived from acetophenone with methyl acrylate **2a** was chosen as a model system of type D to investigate the reaction methods and conditions (Table 1). With the use of lithium enolate (**1**, M = Li), no reaction was observed (entry 1) as expected from the discussion in Scheme 1. In entry 2, the use of silyl enolate (**1**, M = $SiMe_3$) with an equimolar amount of Lewis acid gave the Michael adduct **3aa** in 81% yield (Mukaiyama Michael addition).[7] However, a catalytic amount of Lewis acid or fluoride ion gave low yields of the product (entries 3−5). Surprisingly, when tin enolate (**1**, M = $SnBu_3$) was used as a metal enolate in the presence of a catalytic amount of tetrabutylammonium bromide, the desired product was obtained in 64% yield (entry 7). The reaction without a catalyst did not proceed even at high temperature (entry 6).

Scheme 2

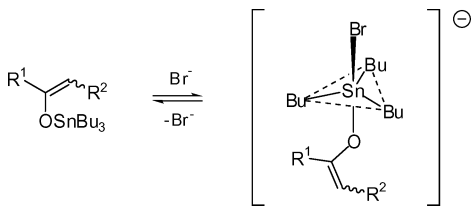
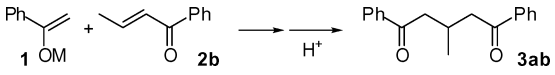


Table 2. Addition of Ketone Enolate to α,β-Unsaturated Ketone[a]



entry	M	additive (mmol)	conditions	yield/%
1	Li		THF, −78 °C, 48 h	80
2	$SiMe_3$	$TiCl_4$ (0.1)	CH_2Cl_2, −78 °C, 2 h	87
3	$SiMe_3$	Bu_4NF (0.1)	THF, −78 °C, 12 h	88
4	$SnBu_3$	Bu_4NBr (0.1)	THF, 63 °C, 12 h	93

[a] Metal enolate **1** (3.0 equiv), enone **2b** (1.0 equiv).

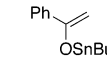
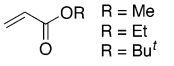
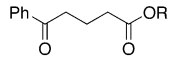
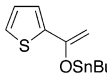
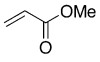
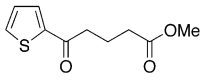
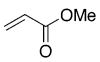
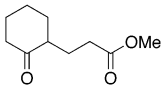
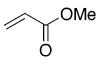
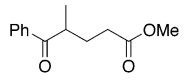
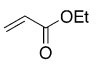
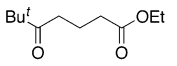
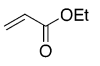
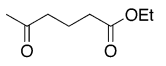
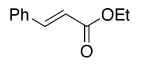
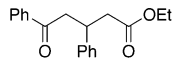
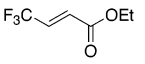
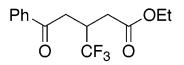
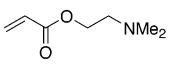
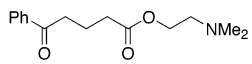
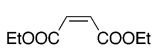
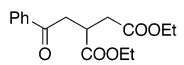
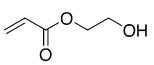
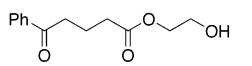
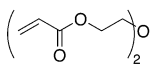
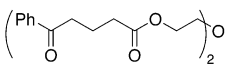
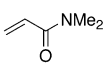
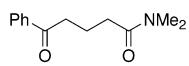
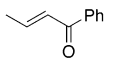
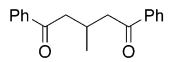
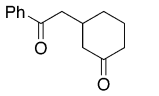
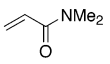
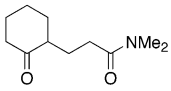
We have been recently developing a bromide anion-coordinated tin enolate, which is characterized by spectroscopic study. High coordination of tin enolate generated by using an equimolar amount of ligands shows a unique nucleophilic character for selective reactions (Scheme 2).[15] This conjugate addition also requires the ligand (bromide anion), and, interestingly, a catalytic amount was enough to complete the reaction.

On the contrary, the reaction of the α,β-unsaturated ketone **2b** with even ketone enolates **1** other than tin enolates took place to give the product **3ab** (Table 2, entries 1−3). The difference can be explained by the thermodynamically favorable reaction course of **1** with unsaturated ketone (type B). The tin enolate−catalytic Bu_4NBr system also proceeded smoothly to give the product in 93% yield (entry 4). It is noted that the reaction system using tin enolate with Bu_4NBr provides a new catalytic pathway for both unsaturated esters and ketones.

We then explored the generality of the Michael addition by varying tin enolates **1** and unsaturated carbonyls **2**. Table 3 summarizes these results. The reaction of **1a** with **2a** was carried out in THF reflux conditions to increase the yield of **3aa** from 64% (Table 1, entry 7) to >99% (Table 3, entry 1). The substituents in the alkoxy moiety on the enoates did not affect the reaction (entries 1−3). The heteroaromatic enolate **1b** gave the desired adduct **3ba** in high yield (entry 4). The reaction of tin enolate **1c** derived from cyclohexanone proceeded even at room temperature to give the product **3ca** quantitatively (entry

(4) The subsequent step such as cyclization after Michael addition contributes to the stabilization of the product system. (a) Miller, J. J.; de Benneville, P. L. *J. Org. Chem.* **1957**, *22*, 1268−1269. (b) Lee, R. A. *Tetrahedron Lett.* **1973**, 3333−3336.
(5) Hashimoto, Y.; Machida, S.; Saigo, K.; Inoue, J.; Hasegawa, M. *Chem. Lett.* **1989**, 943−946.
(6) As expected from this assumption, reaction type A including transformation from ester enolate to ketone enolate shows the largest stabilization.
(7) (a) Narasaka, K.; Soai, K.; Mukaiyama, T. *Chem. Lett.* **1974**, 1223−1224. (b) Narasaka, K.; Soai, K.; Aikawa, Y.; Mukaiyama, T. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 779−783.
(8) (a) Yamazaki, T.; Haga, J.; Kitazume, T.; Nakamura, S. *Chem. Lett.* **1991**, 2175−2178. (b) Yamazaki, T.; Hiraoka, S.; Kitazume, T. *J. Org. Chem.* **1994**, *59*, 5100−5103.
(9) Kobayashi, S.; Mukaiyama, T. *Chem. Lett.* **1987**, 1183−1186.
(10) Kobayashi, S.; Tamura, M.; Mukaiyama, T. *Chem. Lett.* **1988**, 91−94.
(11) Hashimoto, Y.; Mukaiyama, T. *Chem. Lett.* **1986**, 755−758.
(12) (a) Duhamel, L.; Duhamel, P.; Enders, D.; Karl, W.; Leger, F.; Poirier, J. M.; Raabe, G. *Synthesis* **1991**, 649−654. (b) Enders, D.; Karl, W. *Synlett* **1992**, 895−897 and references therein.
(13) A part of this work has been reported in a communication. Yasuda, M.; Ohigashi, N.; Shibata, I.; Baba, A. *J. Org. Chem.* **1999**, *64*, 2180−2181.
(14) Yasuda, M.; Ohigashi, N.; Baba, A. *Chem. Lett.* **2000**, 1266−1267.
(15) (a) Yasuda, M.; Chiba, K.; Baba, A. *J. Am. Chem. Soc.* **2000**, *122*, 7549−7555. (b) Yasuda, M.; Hayashi, K.; Katoh, Y.; Shibata, I.; Baba, A. *J. Am. Chem. Soc.* **1998**, *120*, 715−721. (c) Yasuda, M.; Morimoto, J.; Shibata, I.; Baba, A. *Tetrahedron Lett.* **1997**, *38*, 3265−3266. (d) Yasuda, M.; Katoh, Y.; Shibata, I.; Baba, A.; Matsuda, H.; Sonoda, N. *J. Org. Chem.* **1994**, *59*, 4386-4392. (e) Yasuda, M.; Oh-hata, T.; Shibata, I.; Baba, A.; Matsuda, H. *J. Chem. Soc., Perkin Trans. 1* **1993**, 859−865. (f) Baba, A.; Yasuda, M.; Yano, K.; Shibata, I.; Matsuda, H. *J. Chem. Soc., Perkin Trans. 1* **1990**, 3205−3207. (g) Yasuda, M.; Baba, A. *J. Synth. Org. Chem., Jpn.* **2001**, *59*, 697−706.

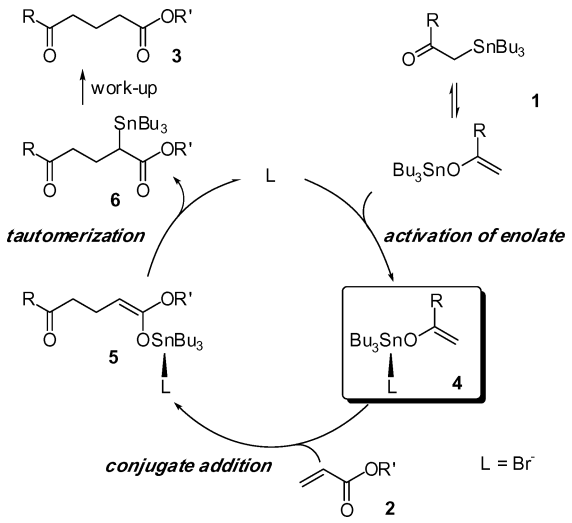
Table 3. Michael Addition of Tin Enolate **1** to α,β-Unsaturated Carbonyls **2** Catalyzed by Bu_4NBr[a]

entry	enolate		unsaturated carbonyl		time/h	product		yield/%
1		**1a**	 R = Me	**2a**	12		**3aa**	>99
2		**1a**	R = Et	**2c**	12		**3ac**	>99
3		**1a**	R = Bu^t	**2d**	12		**3ad**	>99
4		**1b**		**2a**	12		**3ba**	91
5		**1c**		**2a**	14		**3ca**	>99[b]
6		**1d**		**2a**	12		**3da**	86
7		**1e**		**2c**	16		**3ec**	70
8		**1f**		**2c**	19		**3fc**	16
9	**1a**			**2e**	12		**3ae**	0
10	**1a**			**2e**	15		**3ae**	31[c]
11	**1a**			**2f**	12		**3af**	64
12	**1a**			**2g**	13		**3ag**	69
13	**1a**			**2h**	12		**3ah**	71
14	**1a**			**2i**	12		**3ai**	20
15	**1a**			**2j**	6		**3aj**	98[d]
16	**1a**			**2k**	12		**3ak**	62
17	**1a**			**2b**	12		**3ab**	93
18	**1a**			**2l**	12		**3al**	>99
19		**1c**		**2k**	6		**3ck**	91
20		**1d**		**2k**	6		**3dk**	86
21		**1e**		**2m**	16		**3em**	40

[a] The reactions were performed using tin enolate **1** (3.0 mmol), unsaturated carbonyl **2** (1.0 mmol), and Bu_4NBr (0.1 mmol) in THF (10 mL) while refluxing. [b] The reaction was performed at 25 °C. [c] Bu_4NBr (1.8 mmol). [d] **2j** (0.7 mmol).

5). The enolates **1d** and **1e** also afforded the corresponding Michael adducts in high yields (entries 6 and 7). On the contrary, tin enolate **1f** gave a low yield of **3fc** (entry 8). Organotin enolates exist as an equilibrium of keto- and/or enol-forms, and the ratio is dependent on the structure of the enolate.[16] Enol-forms generally show higher reactivity than keto-forms.[17] The fact that **1c** exists only in enol-form and **1f** in keto-form reasonably explains the difference in their reactivity. Loading

Scheme 3. Plausible Reaction Mechanism

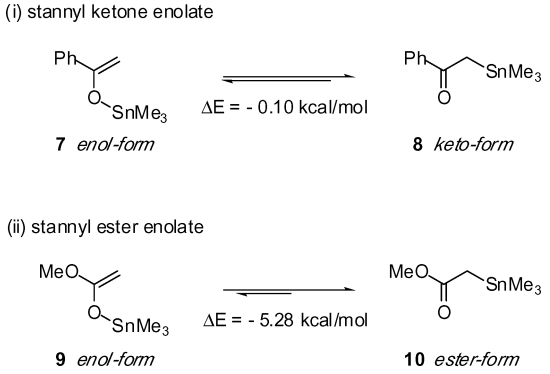


of more than an equimolar amount of tetrabutylammonium bromide was required for the reaction with the β-substituted enoate **2e** (entries 9 and 10). The trifluoromethyl-substituted enoate was applied to the catalytic system because of the stabilization effect of the CF_3 group (entry 11).[8] The amino and hydroxy groups in the substrates **2g** and **2i** tolerated the reaction conditions (entries 12 and 14). The substrate **2j** bearing a dual accepting moiety gave the product **3aj**, which was attacked at both sides (entry 15). This system was applied to α,β-unsaturated amide **2k** to give δ-ketoamides **3ak**, **3ck**, and **3dk** (entries 16, 19, and 20). Unsaturated ketones smoothly converted to δ-diketones **3ab**, **3al**, and **3em** (entries 17, 18, and 21).

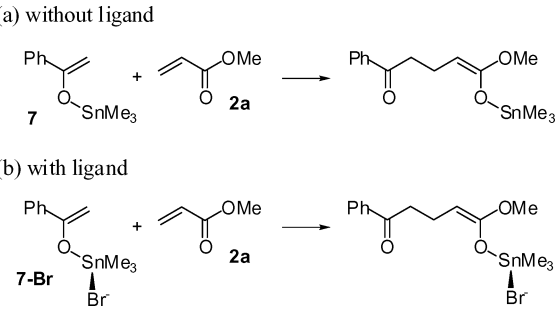
Investigation of the Reaction Mechanism. (a) Catalytic Cycle. Because the type D reaction is thermodynamically disfavored as already described, the present tin enolate−catalytic Bu_4NBr system should require a further step for stabilization of the product system. Hence, we propose a plausible reaction course as illustrated in Scheme 3. The tin enolate **1** exists in keto- and/or enol-forms, and the bromide anion coordinates to only the enol-form to give **4**.[15d] The high coordination enhances the nucleophilicity of enolate and adds to unsaturated ester **2**. After conjugate addition, the resulting Michael adduct **5** includes a stannyl ester enolate (enol-form; O-stannylated form). The ester enolate **5** readily tautomerized to ester-form **6** (C-stannylated form) in which the product system is thermodynamically stabilized. This step takes place with dissociation of the bromide anion because the tin center bearing only carbons is reluctant to accept a bromide ligand.[15d] The product **3** is obtained after workup.

(b) Reaction Step from 5 to 6. The ready tautomerization of the stannyl ester enolate from the enol-form to ester-form (α-stannyl ester) is reported, and ester enolates of tin are usually isolated as only the ester-form, not the enol-form.[18,19] As compared to the ester enolate, stannyl ketone enolates are often isolated as a mixture of keto- and enol-forms.[16] The theoretical calculation shows reasonable results as illustrated in Scheme 4. For the stannyl ketone enolate, the energy difference between

Scheme 4. Tautomerization of Stannyl Enolate



Scheme 5. The Reaction between **7** and **2a** with or without Ligand



7 and **8** is 0.10 kcal/mol. A larger difference (5.28 kcal/mol) between enol-form **9** and ester-form **10** is calculated in ester enolate, and the equilibrium largely lies on the side of the ester-form. This thermodynamic factor in ester enolate significantly affects the step from **5** to **6** in Scheme 3. The unique character of stannyl enolates in tautomerization allows the general synthetic route of the type D reaction, while the reaction with other typical metal enolates failed.

(c) Reaction Step from 4 to 5. Next, the C−C bond formation step from **4** to **5**, which is a rate-determining step, was investigated by theoretical calculation. We assume that the effect of the bromide anion catalyst serves as an accelerator of the Michael addition as shown in Scheme 3. The reaction of four- or five-coordinated tin enolate (**7** or **7-Br**) with α,β-unsaturated ester **2a** was chosen as a model reaction system (Scheme 5). The calculation was performed for the reactions from the starting materials to the Michael adducts which have the enol-form at the ester moiety.

The calculated potential energy profiles for the uncatalyzed and catalyzed reactions corresponding to Scheme 5a and b are shown in Figures 1 and 2, respectively. The optimized geometries for their pathways and the structures in the reaction courses are illustrated in Figures 3 and 4 and Scheme 6.

The activation energy in the reaction using the bromide anion is lower than that of the reaction without using it (18 vs 11 kcal/mol) as shown in Figures 1 and 2. The transition state **A** or **D** in either reaction course has a linear structure, not a cyclic one, with long distances between Sn and O (**A**, 3.808 Å; **D**, 5.576 Å) as shown in Figures 3 and 4. The local minimum corresponding to the intermediate **E** was found in the catalyzed-reaction course from **C** to **G**, while the uncatalyzed reaction directly gave the Michael adduct **B** from the starting materials **7** + **2a**. The structure **E** has a Sn−O bond still at the enol site. The ligand which coordinates to the tin center would decrease

(16) Pereyre, M.; Bellegarde, B.; Mendelsohn, J.; Valade, J. *J. Organomet. Chem.* **1968**, *11*, 97−110.
(17) Kobayashi, K.; Kawanisi, M.; Hitomi, T.; Kozima, S. *Chem. Lett.* **1983**, 851−854.
(18) Zapata, A.; Acuna, C. *Synth. Commun.* **1984**, *14*, 27−32.
(19) Shimada, E.; Inomata, K.; Mukaiyama, T. *Chem. Lett.* **1974**, 689−690.

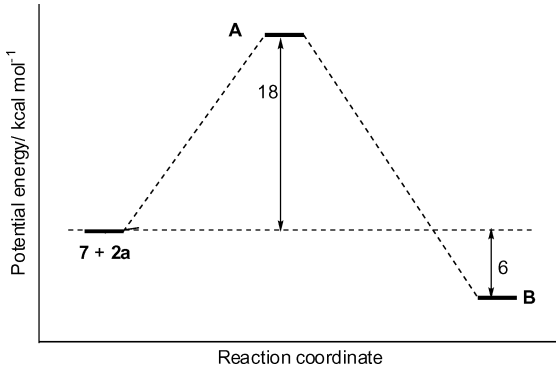


Figure 1. Potential energy profile for the reaction between **7** and **2a** without ligand.

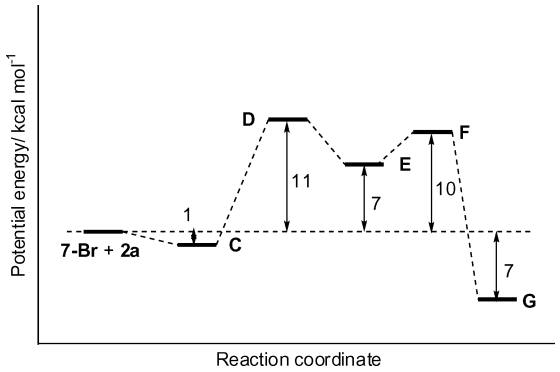


Figure 2. Potential energy profile for the reaction between **7** and **2a** with ligand.

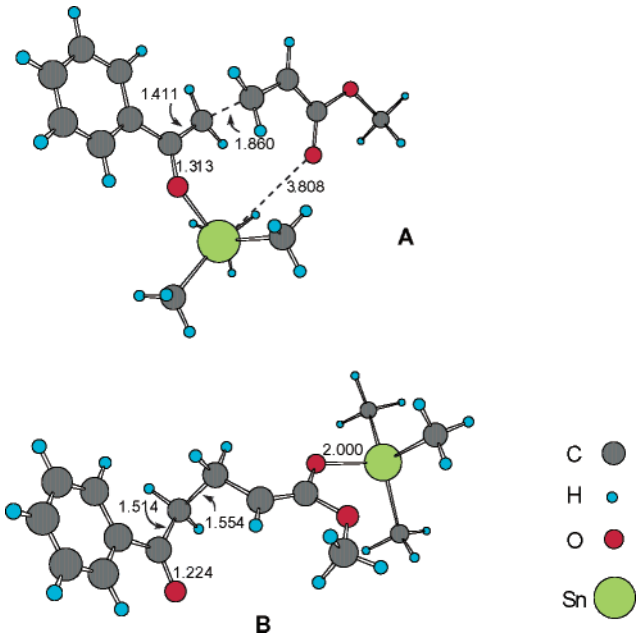


Figure 3. Structures along the reaction between **7** and **2a** (distances in Å).

the Lewis acidity of tin and interfere with a ready transfer of the stannyl group from the enolate oxygen to the ester carbonyl oxygen. The structure of the transition state **F** shows little interaction of the tin center with either oxygen. When the reaction goes forward to **G**, the interaction of Sn with oxygen in the ester enolate moiety becomes stronger and contributes to the stabilization of the potential energy. The Michael adduct **G**

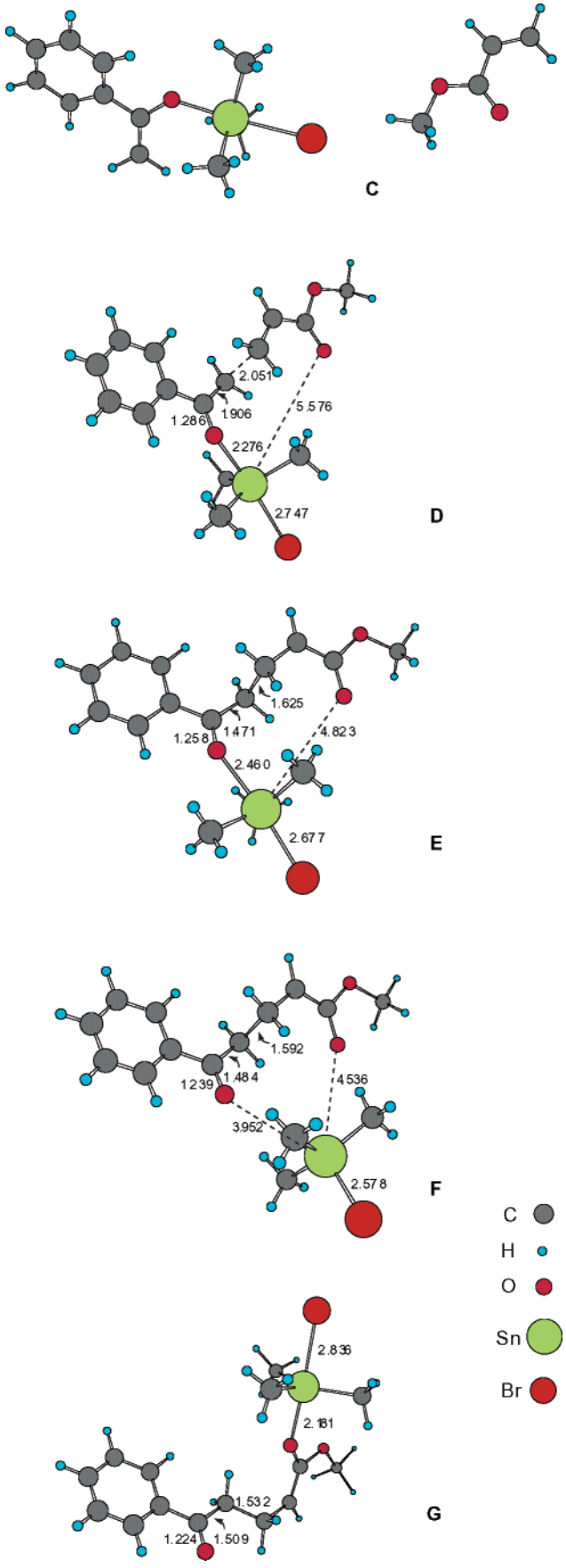
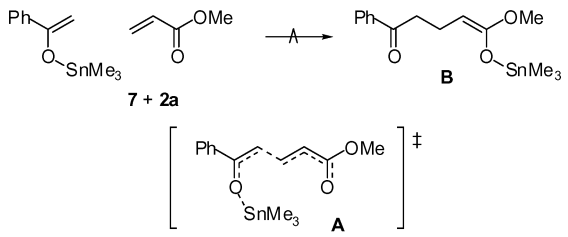


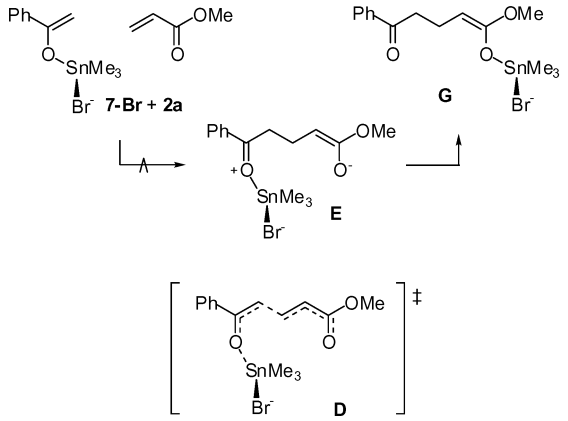
Figure 4. Structures along the reaction between **7-Br** and **2a** (distances in Å).

Scheme 6

(a) Reaction Scheme between **7** and **2a** without ligand



(b) Reaction Scheme between **7** and **2a** with ligand



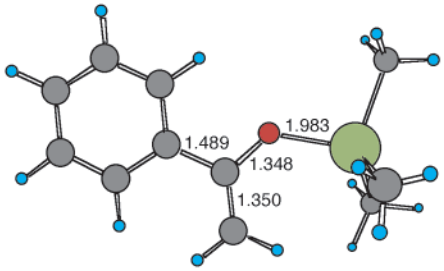
that forms via migration of the stannyl group is thermodynamically stable and finally leads to the more stabilized ester-form.[20]

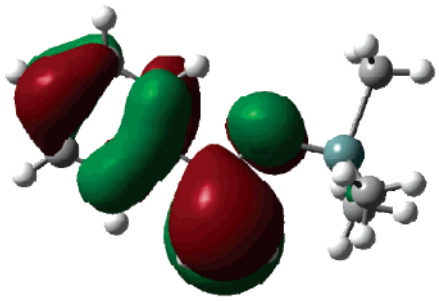
The coordination of the bromide anion to tin enolate causes a significant change in the structure and reactivity.[15a] The structures and HOMOs of four-coordinated enolate **7** and five-coordinated enolate **7-Br** are illustrated in Figure 5. The highly coordinated tin enolate **7-Br** shows longer distance in the O−Sn (1.983−2.150 Å) and vinylic bonds (1.350−1.362 Å) and shorter distance in the C−O bond (1.348−1.317 Å) as compared to four-coordinated species **7**. A four-coordinated tin enolate has partially double bond character in O−Sn by pπ−dπ interaction, which has conjugation with the vinylic moiety such as diene. The coordination of the anionic ligand to the tin center decreases the interaction of the O−Sn bond to generate partially double bond character in the C−O bond. We also show the energies and shapes of the HOMOs of **7** and **7-Br**. The coordination of the bromide anion to the tin center leads to an increment of the HOMO lobe at the vinylic moiety. The energy level of HOMO is increased from −132.3 to −55.4 kcal/mol. These results indicate the significant enhancement of nucleophilicity of tin enolates by coordination of the bromide anion to the tin center.

Conclusions

We have demonstrated that Michael addition of metal ketone enolate to α,β-unsaturated esters successfully proceeds using tin enolate combined with Bu_4NBr-catalyst. An ab initio calculation for this reaction system clarified the details of the reaction course. This system has three mechanistically important points: (1) The coordination of the bromide anion catalyst contributes to the enhancement of the reaction rate to enoates due to an increase of its HOMO level. The activation energy is lowered by the ligand-coordinated system. (2) The product

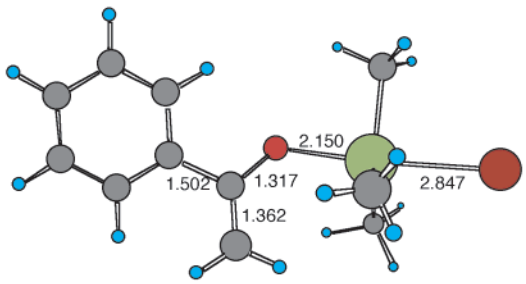
7; tin enolate without ligand

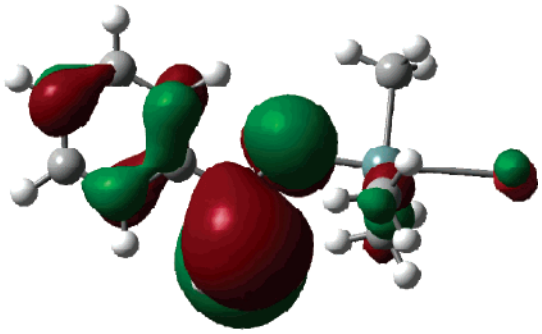




7 HOMO (ε = -132.3 kcal/mol)

7-Br; tin enolate with ligand





7-Br HOMO (ε = -55.4kcal/mol)

Figure 5. Structures of tin enolate **7** and coordinated tin enolate **7-Br** (distances in Å) and HOMOs for each species (ϵ values in parentheses are the energies).

(20) The potential energy profile around the transition state between **E** and **G** is too flat and includes several local energy maximums, whose levels are lower than that of **D**. The structure **F** has the highest energy level among them between **E** and **G**. The difference between the uncatalyzed and catalyzed reactions can be discussed by comparing **A** and **D**.

system has a further stabilization step from the enol-form in the initial adduct to the ester-form by tautomerization of tin enolates. This tautomerization is a unique characteristic of the tin species. (3) The isomerization leads to formation of the keto-form, which releases the bromide anion, and the catalytic cycle can be completed. These points lead to the accomplishment of the first example of the Michael addition type D (ketone enolate + unsaturated ester), which has not been completed before under catalytic conditions. This system can be applied to a variety of tin enolates and α,β-unsaturated carbonyls involving enoates, enones, and unsaturated amides.

Experimental Section

General. IR spectra were recorded as thin films on a Hitachi 260-30 or a HORIBA FT-720 spectrophotometer. ^{1}H and ^{13}C NMR spectra were obtained with a JEOL JNM-GSX-270 (270 and 67.9 MHz) spectrometer, respectively, with TMS as internal standard. Mass spectra were recorded on a JEOL JMS-DS303 or a Shimadzu GCMS-QP2000A spectrometer. GLC analyses were performed on a Shimadzu GC-8A with FID using a 2 m × 3 mm column packed with SE-52. Column chromatography was performed on silica gel (Fuji Silysia BW-200). Bulb-to-bulb distillation (Kugelrohr) was accomplished in a Sibata GTO-250RS at the oven temperature and pressure indicated.

Materials. THF was distilled from sodium and benzophenone. Tin enolates **1a**, **1c**−**f** were prepared by known methods from enol acetate and tributyltin methoxide.[16,21] The tin enolate **1b** was prepared from the corresponding enol acetates (1-acetoxy-1-(2-thienyl)ethene and tributyltin methoxide) in a similar fashion.[16,21] 1-Acetoxy-1-(2-thienyl)-ethene was prepared by the reaction of 2-acetylthiophene with ketene.[22] The Michael acceptors **2** were commercial products except for **2b**. (*E*)-1-Phenyl-2-buten-1-one **2b** was prepared according to the described method.[23]

Addition of Ketone Enolate to 2a or 2b (Tables 1 and 2). (a) M = Li.[24] A flask was charged with dried THF (2 mL) under nitrogen and was cooled to −78 °C. A 2.0 M solution of lithium diisopropylamide (from Aldrich) in THF/heptane/ethylbenzene (1.5 mL) was added. To the mixture was added dropwise acetophenone (3.0 mmol). After 15 min of stirring, **2a** or **2b** (1.0 mmol) was added under the conditions found in Table 1 or 2. The reaction was quenched with 20 mL of aqueous NH_4Cl, and the aqueous phase was extracted with Et_2O.

(b) M = Si with $TiCl_4$.[7a] A solution of $TiCl_4$ (0.5 mmol) in 5 mL of CH_2Cl_2 was cooled to −78 °C and stirred under nitrogen. To the reaction mixture were successively added **2a** or **2b** (0.5 mmol) and silyl enolate (1.5 mmol) under the conditions found in Table 1 or 2. The mixture was quenched with aqueous $KHCO_3$, and the resulted precipitate was filtered off. The aqueous phase was extracted with Et_2O. The other reactions using silyl enolate were perfomed in the same manner.

(c) M = Si with Bu_4NF.[25] A solution of silyl enolate (1.5 mmol) and **2a** or **2b** (0.5 mmol) in 2 mL of THF was kept at the temperatures described in Table 1 or 2 and stirred under nitrogen. To the reaction mixture was added Bu_4NF (0.05 mmol, 1 M in THF). Workup was performed according to the literature.[25]

(d) M = Si with CsF.[26] A solution of CsF (0.05 mmol) in 2 mL of THF was kept at the temperatures described in Table 1 and stirred under nitrogen. To the reaction mixture were successively added **2a** (0.5 mmol) and silyl enolate (1.5 mmol). Workup was performed according to the literature.[26]

General Procedure for Synthesis of δ-Dicarbonyl Compounds (3). To a mixture of a tin enolate **1** (3.0 mmol) and a catalytic amount of tetrabutylammonium bromide (0.1 mmol) in dry THF (10 mL) was added an α,β-unsaturated carbonyl **2** (1.0 mmol) under nitrogen. The reaction mixture was stirred under the conditions noted in Tables 1−3. Methanol (5 mL) was then added to the solution, and the volatiles were evaporated. Diethyl ether (30 mL) and aqueous NH_4F (15%; 15 mL) were added, and the precipitated Bu_3SnF was filtered off. The filtrate was washed with water (30 mL × 2), dried ($MgSO_4$), and evaporated. Column chromatography of the residue on silica gel and distillation or recrystallization gave pure products.

Product Data. The spectral data of the product **3fc** were in excellent agreement with the purchased sample (Aldrich).

Methyl 5-Oxo-5-phenylpentanoate (3aa). According to the general procedure, this compound was prepared from **1a** and **2a** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 1/1). Further purification was performed by distillation under reduced pressure: bp 120 °C/2 mmHg. IR (neat): 1730, 1690 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.98−7.93 (m, 2H, aroma), 7.60−7.42 (m, 3H, aroma), 3.68 (s, 3H, OMe), 3.06 (t, J = 7.3 Hz, 2H, 4-H_2), 2.45 (t, J = 7.3 Hz, 2H, 2-H_2), 2.07 (qn, J = 7.3 Hz, 2H, 3-H_2). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.24 (s, C-5), 173.57 (s, C-1), 136.73 (s, ipso), 132.94 (d), 128.48 (d), 127.90 (d), 51.42 (q, OMe), 37.32 (t, C-4), 33.01 (t, C-2), 19.24 (t, C-3). MS (EI, 70 eV): *m*/*z* 206 (M^+, 2), 175 (M^+ − OMe, 6), 147 (M^+ − COOMe, 7), 133 (3), 105 (100), 77 (47). HRMS (EI, 70 eV): calcd for $C_{12}H_{14}O_3$ 206.0943, found *m*/*z* 206.0943 (M^+). Anal. Calcd for $C_{12}H_{14}O_3$: C, 69.89; H, 6.84. Found: C, 69.59; H, 6.95.

Ethyl 5-Oxo-5-phenylpentanoate (3ac). According to the general procedure, this compound was prepared from **1a** and **2c** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 5/1). Further purification was performed by distillation under reduced pressure: bp 170 °C/2 mmHg. IR (neat): 1736, 1689 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.98−7.95 (m, 2H, aroma), 7.59−7.42 (m, 3H, aroma), 4.14 (q, J = 7.3 Hz, 2H, OCH_2), 3.05 (t, J = 7.3 Hz, 2H, 4-H_2), 2.43 (t, J = 7.3 Hz, 2H, 2-H_2), 2.07 (qn, J = 7.3 Hz, 2H, 3-H_2), 1.25 (t, J = 7.3 Hz, 3H, OCH_2CH_3). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.36 (s, C-5), 173.19 (s, C-1), 136.79 (s, ipso), 132.97 (d), 128.52 (d), 127.93 (d), 60.28 (t, OCH_2), 37.40 (t, C-4), 33.35 (t, C-2), 19.35 (t, C-3), 14.15 (q, OCH_2CH_3). MS (EI, 70 eV): *m*/*z* 220 (M^+, 11), 175 (M^+ − OEt, 25), 147 (M^+ − COOEt, 14), 133 (6), 105 (100), 77 (27). HRMS (EI, 70 eV): calcd for $C_{13}H_{16}O_3$ 220.1099, found *m*/*z* 220.1091, 220.1095, 220.1115 (M^+).

***tert*-Buthyl 5-Oxo-5-phenylpentanoate (3ad).** According to the general procedure, this compound was prepared from **1a** and **2d** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 10/1). Further purification was performed by distillation under reduced pressure: bp 160 °C/2 mmHg. IR (neat): 1728, 1689 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.98−7.95 (m, 2H, aroma), 7.59−7.43 (m, 3H, aroma), 3.06 (t, J = 6.8 Hz, 2H, 4-H_2), 2.34 (t, J = 6.8 Hz, 2H, 2-H_2), 2.03 (qn, J = 6.8 Hz, 2H, 3-H_2), 1.45 (s, 9H, ^{t}Bu). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.55 (C-5), 172.56 (C-1), 136.88 (ipso), 132.97, 128.54, 127.99, 80.24 (CMe_3), 37.49 (C-4), 34.66 (C-2), 28.09 (CMe_3), 19.62 (C-3). MS (EI, 70 eV): *m*/*z* 248 (M^+, 0.08), 175 (M^+ − O^{t}Bu, 67), 147 (M^+ − COO^{t}Bu, 22), 133 (12), 105 (100), 77 (29). HRMS (EI, 70 eV): calcd for $C_{15}H_{20}O_3$ 248.1412, found *m*/*z* 248.1440, 248.1425 (M^+). Anal. Calcd for $C_{15}H_{20}O_3$: C, 72.55; H, 8.12. Found: C, 72.38; H, 7.98.

Methyl 5-(2-Thienyl)-5-oxopentanoate (3ba). According to the general procedure, this compound was prepared from **1b** and **2a** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 2/1). Further purification was performed by distillation under reduced pressure: bp 155 °C/2 mmHg. IR (neat): 1682, 1730 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.74−7.71 (m, 1H, aroma), 7.65−7.61 (m, 1H, aroma), 7.15−7.11 (m, 1H, aroma), 3.68 (s, 3H, OMe), 2.99 (t, J = 7.3 Hz, 2H, 4-H_2), 2.44 (t, J = 7.3 Hz, 2H, 2-H_2), 2.08

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(qn, J = 7.3 Hz, 2H, 3-H_2). ^{13}C NMR (67.9 MHz, $CDCl_3$): 192.32 (C-5), 173.55 (C-1), 144.12, 133.52, 131.86, 128.07, 51.54 (OMe), 38.13 (C-4), 33.01 (C-2), 19.64 (C-3). MS (EI, 70 eV): *m*/*z* 212 (M^+, 10), 181 (M^+ − OMe, 12), 153 (M^+ − COOMe, 12), 139 (10), 111 (100), 83 (83). HRMS (EI, 70 eV): calcd for $C_{10}H_{12}O_3S$ 212.0507, found *m*/*z* 212.0509 (M^+). Anal. Calcd for $C_{10}H_{12}O_3S$: C, 56.59; H, 5.70. Found: C, 56.44; H, 5.89.

Methyl 3-(2-Oxocyclohexyl)propanoate (3ca). According to the general procedure, this compound was prepared from **1c** and **2a** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 2/1). Further purification was performed by distillation under reduced pressure: bp 105 °C/2 mmHg. IR (neat): 1743, 1712 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 3.66 (OMe, 3H), 2.50−1.37 (m, 13H). ^{13}C NMR (67.9 MHz, $CDCl_3$): 212.40 (s, cycloC═O), 173.91 (s, C-1), 51.38 (q, OMe), 49.63 (d, CH), 42.04 (t), 34.06 (t), 31.53 (t), 27.94 (t), 24.96 (t), 24.74 (t). MS (EI, 70 eV): *m*/*z* 184 (M^+, 24), 153 (M^+ − OMe, 41), 152 (100), 125 (M^+ − COOMe, 20), 124 (43), 111 (24), 97 (19). HRMS (EI, 70 eV): calcd for $C_{10}H_{16}O_3$ 184.1099, found *m*/*z* 184.1095 (M^+). Anal. Calcd for $C_{10}H_{16}O_3$: C, 65.19; H, 8.75. Found: C, 65.47; H, 8.95.

Methyl 4-Methyl-5-oxo-5-phenylpentanoate (3da). According to the general procedure, this compound was prepared from **1d** and **2a** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 5/1). Further purification was performed by distillation under reduced pressure: bp 155 °C/2 mmHg. IR (neat): 1735, 1681 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.97−7.95 (m, 2H, aroma), 7.60−7.40 (m, 3H, aroma), 3.65 (s, 3H, OMe), 3.6−3.5 (m, 1H, 4-H), 2.47−2.26 (m, 2H, 2-H_2), 2.24−2.10 (m, 1H, 3-H^A), 1.85−1.71 (m, 1H, 3-H^B), 1.21 (d, J = 6.83 Hz, 3H, 4-Me). ^{13}C NMR (67.9 MHz, $CDCl_3$): 203.46 (s, C-5), 173.68 (s, C-1), 136.33 (s, ipso), 133.00 (d), 128.65 (d), 128.28 (d), 51.50 (q, OMe), 39.53 (d, C-4), 31.45 (t, C-2), 28.24 (t, C-3), 17.32 (q, 4-Me). MS (EI, 70 eV): *m*/*z* 220 (M^+, 17), 189 (M^+ − OMe, 10), 161 (M^+ − COOMe, 5), 147 (3), 105 (100), 77 (24). HRMS (EI, 70 eV): calcd for $C_{13}H_{16}O_3$ 220.1099, found *m*/*z* 220.1102 (M^+). Anal. Calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.61; H, 7.34.

Ethyl 6,6-Dimethyl-5-oxoheptanoate (3ec). According to the general procedure, this compound was prepared from **1e** and **2c** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 5/1). Further purification was performed by distillation under reduced pressure: bp 80 °C/2 mmHg. IR (neat): 1736, 1705 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 4.13 (q, J = 7.3 Hz, 2H, OCH_2-CH_3), 2.56 (t, J = 7.3 Hz, 2H, 4-H_2), 2.31 (t, J = 7.3 Hz, 2H, 2-H_2), 1.88 (qn, J = 7.3 Hz, 2H, 3-H_2), 1.25 (t, J = 7.3 Hz, 3H, OCH_2CH_3), 1.13 (s, ^{t}Bu). ^{13}C NMR (67.9 MHz, $CDCl_3$): 215.22 (C-5), 173.32 (C-1), 60.27 (OCH_2CH_3), 44.06 (C-6), 35.29, 33.33, 26.35 (CMe_3), 19.14 (C-3), 14.22 (OCH_2CH_3). MS (EI, 70 eV): *m*/*z* 200 (M^+, 0.14), 155 (M^+ − OEt, 23), 143 (100), 127 (4), 115 (71). HRMS (EI, 70 eV): calcd for $C_{11}H_{20}O_3$ 200.1412, found *m*/*z* 200.1423, 200.1387 (M^+).

Ethyl 3-Phenyl-5-oxo-5-phenylpentanoate (3ae). According to the general procedure, this compound was prepared from **1a** and **2e** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 2/1). A solid was obtained after standing for 1 day and quickly washed by hexane to give the pure product: mp 60 °C. IR (KBr): 1728, 1674 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.93−7.89 (m, 2H, aroma), 7.57−7.16 (m, 8H, aroma), 4.03 (q, J = 7.3 Hz, 2H, OCH_2), 3.88 (qn, J = 7.3 Hz, 1H, 3-H), 3.40 (dd, J = 16.6, 7.3 Hz, 1H, 4-H^A), 3.32 (dd, J = 16.6, 7.3 Hz, 1H, 4-H^B), 2.81 (dd, J = 15.6, 7.3 Hz, 1H, 2-H^A), 2.67 (dd, J = 15.6, 7.3 Hz, 1H, 2-H^B), 1.13 (t, J = 7.3 Hz, 3H, OCH_2CH_3). ^{13}C NMR (67.9 MHz, $CDCl_3$): 198.09 (C-5), 171.77 (C-1), 143.28, 136.88, 133.01, 128.51, 128.00, 127.33, 126.71, 60.31 (OCH_2), 44.55, 40.76, 37.55, 14.03 (Me). MS (EI, 70 eV): *m*/*z* 296 (M^+, 17), 251 (M^+ − OEt, 13), 223 (M^+ − COOEt, 5), 209 (42), 177 (5), 105 (100), 77 (27). HRMS (EI, 70 eV): calcd for $C_{19}H_{20}O_3$ 296.1413, found *m*/*z* 296.1425, 296.1421 (M^+). Anal. Calcd for $C_{19}H_{20}O_3$: C, 77.00; H, 6.80. Found: C, 76.85; H, 6.75.

Ethyl 3-Trifluoromethyl-5-oxo-5-phenylpentanoate (3af). According to the general procedure, this compound was prepared from **1a** and **2f** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 5/1). Further purification was performed by distillation under reduced pressure: bp 125 °C/2 mmHg. IR (neat): 1736, 1689 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.99−7.95 (m, 2H, aroma), 7.64−7.26 (m, 3H, aroma), 4.14 (q, J = 7.3 Hz, 2H, OCH_2), 3.75−3.45 (m, 1H, 3-H), 3.34 (dd, J = 18.6, 4.9 Hz, 1H, 4-H^A), 3.25 (dd, J = 18.6, 7.8 Hz, 1H, 4-H^B), 2.69 (dd, J = 16.1, 5.9 Hz, 1H, 2-H^A), 2.53 (dd, J = 16.1, 7.3 Hz, 1H, 2-H^B), 1.23 (t, J = 7.3 Hz, 3H, Me). ^{13}C NMR (67.9 MHz, $CDCl_3$): 195.62 (C-5), 170.24 (C-1), 136.18 (ipso), 133.52, 128.69, 128.00, 127.40 (q, $^1J_{CF}$ = 279.2 Hz, CF_3), 60.99 (OCH_2), 36.55 (C-4), 35.76 (q, $^2J_{CF}$ = 28 Hz, C-3), 33.15 (t, $^3J_{CF}$ = 3.1 Hz, C-2), 13.94 (q, Me). MS (EI, 70 eV): *m*/*z* 288 (M^+, 8), 243 (M^+ − OEt, 29), 215 (M^+ − COOEt, 18), 105 (100), 77 (27). HRMS (EI, 70 eV): calcd for $C_{14}H_{15}F_3O_3$ 288.0973, found *m*/*z* 288.0956, 288.0971 (M^+). Anal. Calcd for $C_{14}H_{15}F_3O_3$: C, 58.33; H, 5.24. Found: C, 58.10; H, 5.10.

2-(*N*,*N*-Dimethylamino)ethyl 5-Oxo-5-phenylpentanoate (3ag). According to the general procedure, this compound was prepared from **1a** and **2g** in dry THF to give the product as a colorless liquid after chromatography (Et_2O). Further purification was performed by distillation under reduced pressure: bp 180 °C/2 mmHg. IR (neat): 1736, 1689 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.98−7.94 (m, 2H, aroma), 7.59−7.42 (m, 3H, aroma), 4.18 (t, J = 5.9 Hz, 2H, OCH_2), 3.06 (t, J = 6.8 Hz, 2H, 4-H_2), 2.55 (t, J = 5.9 Hz, 2H, CH_2NMe_2), 2.47 (t, J = 6.8 Hz, 2H, 2-H_2), 2.28 (s, 6H, NMe_2), 2.07 (qn, J = 6.8 Hz, 2H, 3-H_2). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.27 (C-5), 173.19 (C-1), 136.71 (ipso), 132.92, 128.36, 127.90, 62.04 (OCH_2), 57.70 (CH_2NMe_2), 45.59 (NMe_2), 37.32 (C-4), 33.19 (C-2), 19.26 (C-3). MS (EI, 70 eV): *m*/*z* 263 (M^+, 0.3), 219 (M^+ − NMe_2, 0.3), 175 (2), 147 (2), 105 (17), 77 (11), 58 (100). HRMS (EI, 70 eV): calcd for $C_{15}H_{21}O_3N$ 263.1521, found *m*/*z* 263.1526, 263.1537 (M^+). Anal. Calcd for $C_{15}H_{21}O_3N$: C, 68.42; H, 8.04; N, 5.32. Found: C, 68.36; H, 8.05; N, 5.16.

2-(2-Oxo-2-phenylethyl)succinic Acid Diethyl Ester (3ah). According to the general procedure, this compound was prepared from **1a** and **2h** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 1/1). Further purification was performed by distillation under reduced pressure: bp 185 °C/2 mmHg. IR (neat): 1736, 1689 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.99−7.95 (m, 2H, aroma), 7.61−7.43 (m, 3H, aroma), 4.21−4.10 (m, 4H, 2 × OCH_2), 3.58−3.42 (m, 3H, PhCOCH^A and 2-H), 3.25 (dd, J = 16.6, 4.4 Hz, 1H, PhCOCH^B), 2.80 (dd, J = 16.6, 6.3 Hz, 1H, 3-H^A), 2.68 (d, J = 16.6, 6.3 Hz 1H, 3-H^B), 1.28−1.20 (m, 6H, 2 × Me). ^{13}C NMR (67.9 MHz, $CDCl_3$): 197.42 (Ph*C*O), 173.68, 171.58, 136.47 (ipso), 133.23, 128.55, 127.99, 60.93 (OCH_2), 60.62 (OCH_2), 39.27 (PhCO*C*H_2), 36.69 (C-2), 35.41 (C-3), 14.09 (Me), 14.00 (Me). MS (EI, 70 eV): *m*/*z* 292 (M^+, 2), 247 (M^+ − OEt, 39), 187 (17), 105 (100), 77 (20). HRMS (EI, 70 eV): calcd for $C_{16}H_{20}O_5$ 292.1311, found *m*/*z* 292.1316, 292.1293, 292.1294, 292.1296 (M^+). Anal. Calcd for $C_{16}H_{20}O_5$: C, 65.74; H, 6.90. Found: C, 65.58; H, 6.89.

2-Hydroxyethyl 5-Oxo-5-phenylpentanoate (3ai). According to the general procedure, this compound was prepared from **1a** and **2i** in dry THF to give the product as a colorless liquid after chromatography (Et_2O). Further purification was performed by distillation under reduced pressure: bp 170 °C/2 mmHg. IR (neat): 3479, 1728, 1682 cm^{-1}. ^{1}H NMR (270 MHz, $CDCl_3$): 7.97−7.94 (m, 2H, aroma), 7.59−7.42 (m, 3H, aroma), 4.22 (t, J = 4.4 Hz, 2H, $COOCH_2$), 3.82 (t, J = 4.4 Hz, 2H, CH_2OH), 3.06 (t, J = 6.8 Hz, 2H, 4-H_2), 2.69 (brs, 1H, OH), 2.48 (t, J = 6.8 Hz, 2H, 2-H_2), 2.08 (qn, J = 6.8 Hz, 2H, 3-H_2). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.61 (C-5), 173.48 (C-1), 136.59 (ipso), 133.09, 128.54, 127.96, 65.95 ($COOCH_2$), 60.91 (CH_2OH), 37.29 (C-4), 33.18 (C-2), 19.27 (C-3). MS (EI, 70 eV): *m*/*z* 236 (M^+, 7), 175 (M^+ − OC_2H_4OH, 32), 147 (M^+ − $C_3H_5O_3$, 12), 105 (100), 77 (25). HRMS (EI, 70 eV): calcd for $C_{13}H_{16}O_4$ 236.1048, found *m*/*z* 236.1066,

236.1025, 263.1044, 236.1051 (M^+). Anal. Calcd for $C_{13}H_{16}O_4$: C, 66.09; H, 6.83. Found: C, 66.11; H, 6.80.

Tetracarbonyl Compound 3aj. According to the general procedure, this compound was prepared from **1a** and **2j** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 1/1). Further purification was performed by distillation under reduced pressure: bp 220 °C/3.8 × 10^{-2} mmHg. IR (neat): 1732, 1681 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 7.98−7.93 (m, 4H, aroma), 7.59−7.27 (m, 6H, aroma), 4.23 (t, J = 4.9 Hz, 4H, 2 × $COOCH_2$), 3.68 (t, J = 4.9 Hz, 4H, 2 × $COOCH_2CH_2$), 3.06 (t, J = 7.3 Hz, 4H, 2 × $PhCOCH_2$), 2.47 (t, J = 7.3 Hz, 4H, 2 × CH_2COO), 2.07 (t, J = 7.3 Hz, 2 × $PhCOCH_2CH_2$). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.32 (s, Ph*C*O), 173.13 (COO), 136.73 (ipso), 133.03, 128.54, 127.96, 68.99 (OCH_2), 63.31 (OCH_2), 37.35 ($PhCOCH_2$), 33.16 ($OCOCH_2$), 19.24 ($PhCOCH_2CH_2$). MS (CI, 70 eV): *m*/*z* 455 (M^+ + 1, 3), 335 (49), 235 (6), 219 (9), 147 (6), 105 (18). HRMS (CI, 70 eV): calcd for $C_{26}H_{31}O_7$ 455.2070, found *m*/*z* 455.2048, 455.2052 (M^+ + 1). Anal. Calcd for $C_{26}H_{30}O_7$: C, 68.71; H, 6.65. Found: C, 69.01; H, 6.66.

***N,N*-Dimethyl-5-oxo-5-phenylpentanamide (3ak).** According to the general procedure, this compound was prepared from **1a** and **2k** in dry THF to give the product as a colorless liquid after chromatography using [Fuji Silysia FL100DX] (hexane/Et_2O, 1/1). Further purification was performed by distillation under reduced pressure: bp 130 °C/1.5 × 10^{-1} mmHg. IR (neat): 1682, 1643 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 8.01−7.96 (m, 2H, aroma), 7.59−7.40 (m, 3H, aroma), 3.11 (t, J = 6.8 Hz, 2H, 4-H_2), 3.01 (s, 3H, NMe^A), 2.95 (s, 3H, NMe^B), 2.44 (t, J = 6.8 Hz, 2H, 2-H_2), 2.09 (qn, J = 6.8 Hz, 2H, 3-H_2). ^{13}C NMR (67.9 MHz, $CDCl_3$): 200.14 (C-5), 172.45 (C-1), 136.88 (ipso), 132.99, 128.55, 128.08, 37.76 (C-4), 37.18 (NMe^A), 35.33 (NMe^B), 32.32 (C-2), 19.62 (C-3). MS (EI, 70 eV): *m*/*z* 219 (M^+, 26), 175 ($M^+ - NMe_2$, 12), 147 ($M^+ - CONMe_2$, 32), 105 (100), 77 (41). HRMS (EI, 70 eV): calcd for $C_{13}H_{17}NO_2$ 219.1259, found *m*/*z* 219.1255 (M^+).

1,5-Diphenyl-3-methyl-1,5-pentanedione (3ab). According to the general procedure, this compound was prepared from **1a** and **2b** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 5/1). Further purification was performed by distillation under reduced pressure: bp 165 °C/3.5 × 10^{-2} mmHg. IR (neat): 1678 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 8.02−7.98 (m, 4H, aroma), 7.60−7.43 (m, 6H, aroma), 3.23−3.13 (m, 2H, 2-H^A and 4-H^A), 2.93−2.81 (m, 3H, 2-H^B, 4-H^B, and 3-H), 1.09 (d, J = 5.9 Hz, 3H, 3-Me). ^{13}C NMR (67.9 MHz, $CDCl_3$): 199.64 (s, C-1 and C-5), 137.02 (s, ipso), 133.03 (d), 128.59 (d), 128.17 (d), 45.37 (t, C-2 and C-4), 26.62 (d, C-3), 20.27 (q, 3-Me). MS (EI, 70 eV): *m*/*z* 266 (M^+, 0.7), 161 (2), 147 (51), 105 (100), 77 (55). HRMS (EI, 70 eV): calcd for $C_{18}H_{18}O_2$ 266.1307, found *m*/*z* 266.1302 (M^+). Anal. Calcd for $C_{18}H_{18}O_2$: C, 81.17; H, 6.81. Found: C, 80.93; H, 6.96.

3-(2-Oxo-2-phenylethyl)cyclohexanone (3al). According to the general procedure, this compound was prepared from **1a** and **2l** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 1/1). Further purification was performed by distillation under reduced pressure: bp 185 °C/2.8 × 10^{-2} mmHg. IR (neat): 1710, 1680 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 7.95−7.92 (m, 2H, aroma), 7.60−7.40 (m, 3H, aroma), 3.04 (dd, J = 16.1, 6.8 Hz, 1H, $PhCOCH^A$), 2.94 (dd, J = 16.1, 5.8 Hz, 1H, $PhCOCH^B$), 2.6−1.4 (m, 9H, ring). ^{13}C NMR (67.9 MHz, $CDCl_3$): 210.62 (s, C-1), 198.38 (s, Ph*C*O), 136.96 (s, ipso), 133.22 (d), 128.66 (d), 128.04 (d), 47.77 (t, $PhCOCH_2$), 44.68 (t, C-2), 41.23 (t, C-6), 34.87 (d, C-3), 31.12 (t, C-4), 24.88 (t, C-5). MS (EI, 70 eV): *m*/*z* 216 (M^+, 14), 120 (56), 105 (100), 96 (33), 77 (36). HRMS (EI, 70 eV): calcd for $C_{14}H_{16}O_2$ 216.1150, found *m*/*z* 216.1161 (M^+). Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.58; H, 7.47.

***N,N*-Dimethyl 3-(2-Oxocyclohexyl)propanamide (3ck).** According to the general procedure, this compound was prepared from **1c** and **2k** in dry THF to give the product as a colorless liquid after chromatography (Et_2O). Further purification was performed by distillation under reduced pressure: bp 120 °C/2 mmHg. IR (neat): 1705, 1643 cm^{-1}. ^1H NMR (270 Hz, $CDCl_3$): 3.02 (NMe^A, 3H), 2.93 (NMe^B, 3H), 2.48−1.39 (m, 13H). ^{13}C NMR (67.9 Hz, $CDCl_3$): 213.48 (s, cycloCO), 172.87 (s, C-1), 49.99 (d, CH), 42.19 (t), 37.17 (q), 35.24 (q), 34.58 (t), 31.02 (t), 28.10 (t), 25.35 (t), 24.96 (t). MS (EI, 70 eV): *m*/*z* 197 (M^+, 24), 153 ($M^+ - NMe_2$, 4), 125 ($M^+ - CONMe_2$, 14), 100 (20), 97 (3), 72 (26). HRMS (EI, 70 eV): calcd for $C_{11}H_{19}NO_2$ 197.1416, found *m*/*z* 197.1407, 197.1407 (M^+). Anal. Calcd for $C_{11}H_{19}NO_2$: C, 66.97; H, 9.71; N, 7.10. Found: C, 64.96; H, 9.67; N, 6.79.

***N,N*-Dimethyl 4-Methyl-5-oxo-5-phenylpentanamide (3dk).** According to the general procedure, this compound was prepared from **1d** and **2k** in dry THF to give the product as a colorless liquid after chromatography (Et_2O). Further purification was performed by distillation under reduced pressure: bp 170 °C/2 mmHg. IR (neat): 1682, 1643 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 8.02−7.98 (m, 2H, aroma), 7.59−7.44 (m, 3H, aroma), 3.68 (qt, J = 6.8, 5.9 Hz, 1H, 4-H), 2.93 (s, 3H, NMe^A), 2.92 (s, 3H, NMe^B), 2.47−2.08 (m, 3H, 2-H_2 and 3-H^A), 1.91−1.76 (m, 1H, 3-H^B), 1.22 (d, J = 6.8 Hz, 3H, 4-Me). ^{13}C NMR (67.9 MHz, $CDCl_3$): 204.14 (C-5), 172.44 (C-1), 136.45 (ipso), 132.96, 128.63, 128.36, 39.75 (C-4), 37.14 (NMe^A), 35.33 (NMe^B), 30.55 (C-2), 28.59 (C-3), 17.59 (4-Me). MS (EI, 70 eV): *m*/*z* 233 (M^+, 14), 189 ($M^+ - NMe_2$, 4), 161 ($M^+ - CONMe_2$, 10), 128 (19), 105 (100), 77 (33), 72 (56). HRMS (EI, 70 eV): calcd for $C_{14}H_{19}NO_2$ 233.1416, found *m*/*z* 233.1401, 233.1395 (M^+). Anal. Calcd for $C_{14}H_{19}NO_2$: C, 72.07; H, 8.21; N, 6.00. Found: C, 72.15; H, 8.15; N, 6.00.

2,2-Dimethyl-3,7-dioxo-5,7-diphenylheptane (3em). According to the general procedure, this compound was prepared from **1e** and **2m** in dry THF to give the product as a colorless liquid after chromatography (hexane/Et_2O, 2/1). Further purification was performed by distillation under reduced pressure: bp 175 °C/4.0 × 10^{-2} mmHg. IR (neat): 1689 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 8.00−7.90 (m, 2H, aroma), 7.56−7.13 (m, 8H, aroma), 3.91 (qn, J = 6.8 Hz, 1H, 5-H), 3.38 (dd, J = 16.1, 6.8 Hz, 1H, 6-H^A), 3.26 (dd, J = 16.1, 7.3 Hz, 1H, 6-H^B), 2.93 (d, J = 6.8 Hz, 2H, 4-H_2), 1.04 (s, 9H, C*Me*$_3$). ^{13}C NMR (67.9 MHz, $CDCl_3$): 213.85 (C-3), 198.60 (C-7), 143.97 (ipso), 136.84 (ipso), 132.91, 128.46, 128.40, 128.05, 127.41, 126.46, 44.52, 44.03 (C-2), 42.85, 36.65, 26.06 (C*Me*$_3$). MS (EI, 70 eV): *m*/*z* 308 (M^+, 36), 251 ($M^+ - {}^t$Bu, 63), 209 ($M^+ - {}^t$BuCOCH$_2$, 34), 189 (58), 131 (100). HRMS (EI, 70 eV): calcd for $C_{21}H_{24}O_2$ 308.1776, found *m*/*z* 308.1772, 308.1777 (M^+). Anal. Calcd for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found: C, 81.57; H, 7.79.

1-(2-Thienyl)-ethen-1-ol Acetate. bp 34 °C/2 mmHg. IR (neat): 1766, 1635, 1195 cm^{-1}. ^1H NMR (270 MHz, $CDCl_3$): 7.26−7.22 (m, 1H, aroma), 7.12−7.09 (m, 1H, aroma), 6.99−6.95 (m, 1H, aroma), 5.38 (d, J = 2.4 Hz, 1H, 2-H^A), 4.94 (d, J = 2.4 Hz, 1H, 2-H^B), 2.27 (s, 3H, COMe). ^{13}C NMR (67.9 MHz, $CDCl_3$): 168.66 (CO), 147.65 (C-1), 138.13, 127.42, 125.77, 124.64, 101.16 (C-2), 20.82 (Me). MS (EI, 70 eV): *m*/*z* 168 (M^+, 26), 125 ($M^+ - OMe$, 100), 109 ($M^+ - OCOMe$, 6), 83 ($C_4H_3S^+$, 20), 43 (33). HRMS (EI, 70 eV): calcd for $C_8H_8O_2S$ 168.0245, found *m*/*z* 168.0251 (M^+).

Computational Method. We applied the HF/DFT hybrid method originally proposed by Becke,[27] referenced as a B3PW91 three-parameter hybrid functional. All calculations were performed with Gaussian 98 revision A.7.[28] For basis sets, 6-31+G(d) was employed for H, C, O, and Br atoms, and LanL2DZ was employed for Sn,

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respectively. All energies were calculated including the zero point energy correction by the normal-mode analysis for each structure.

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Supporting Information Available: Listing of absolute energies and geometries for calculated species (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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