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Reaction of Selenium Dioxide with Aromatic Ketones in the Presence of Boron Triflouride Etherate: A Protocol for the Synthesis of Triarylethanones

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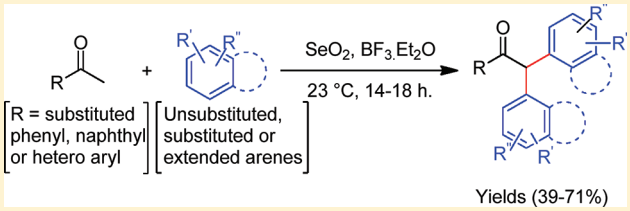
Supporting Information

ABSTRACT: An efficient regioselective protocol for the C−C bond formation by the unexpected α,α-diarylation of aromatic ketones with unactivated arenes in the presence of selenium dioxide and boron trifluoride etherate has been developed. The generality and functional tolerance of this protocol is demonstrated by the synthesis of a series of triarylethanones.



The direct insertion of an aryl moiety next to a carbonyl group has been a long-standing problem in synthetic organic chemistry.[1] The last two decades have seen a lot of effort directed toward achieving a reliable method for the α-arylation of ketones, as this reaction constitutes the key step in the synthesis of a wide number of complex systems.[2] Many new methodologies involving the use of palladium-based catalysts have been developed to achieve this goal. Prominent among them are the works of Buchwald,[3] Dominguez,[4] Hartwig,[5] and Miura.[6] While many of the methods described are quite effective, their practicality is diminished by the time and cost needed to prepare the reagents in stoichiometric amounts. Furthermore, many of these procedures start from the already monoarylated ketones and aryl or pseudohalides.[7]

On the basis of our earlier work on the $BF_3{\cdot}Et_2O$-assisted oxyplumbation studies, which led to the 1,2-carbonyl transposition of acetophenones,[8] we were curious to know whether selenium dioxide under similar reaction conditions would provide the intermediate that could lead to similar rearrangement. To our surprise, the reaction led to an unexpected α,α-diarylation of the ketone to afford triarylethanones **3**, the structural analogues of the cancer therapy agent tamoxifen,[9] in good yields (Table 1). To the best of our knowledge, the use of selenium dioxide and boron trifluoride etherate combination for the direct α,α-diarylation of aromatic ketones has not been reported. The new method we report herein is therefore highly significant, quite general, and proceeds efficiently at ambient temperature and ordinary reaction conditions. In contrast to the general observation that electrophilic aromatic substitutions give mixtures of regioisomers, we are able to isolate only one regioisomer in all of the reactions carried out except in the case of toluene, where trace amount of the *ortho* isomer is detected (as is clear form the ^{1}H and ^{13}C NMR). The attractiveness of the method is further augmented by the fact that the starting materials used are quite common and inexpensive.

Thus, treatment of *p*-chloroacetophenone (**1a**, 1 equiv) with selenium dioxide (1 equiv) in the presence of boron trifluoride etherate (49%, 2 equiv) and substrate **2a** (16 mL) at room temperature for 18 h afforded 1-(4-chlorophenyl)-2,2-dipheny-lethanone (**3a**) in good yield (60%) (entry 1, Table 1). The structure of **3a** was assigned based on ^{1}H, ^{13}C NMR spectroscopy, as well as by comparison with literature data[10,11] and confirmed by single-crystal X-ray diffraction analysis (included in the Supporting Information). It may be mentioned here that boron trifluoride etherate appears to be specific for these reactions since the use of other Lewis acids ($AlCl_3$, $SnCl_4$) either gave no reaction or resulted in the formation of multiple products that are difficult to isolate. Similarly, the reaction of **1b** (R^1 = 4-CH_3), **1d** (R^1 = 3-NO_2), and **1g** (R^1 = 4-OCH_3) with selenium dioxide and boron trifluoride etherate in excess benzene (**2a**) at room temperature for 18 h proceeded smoothly to give the trisubstituted ethanones **3b**, **3d**, and **3g**, respectively, in moderate to good yields (entries 2, 4, and 7, Table 1).

Encouraged by these results, we turned our attention to other substituted benzenes. Interestingly, the nature and position of the substituents on the aromatic ketone does not appear to affect the reaction. It may be also noted that deactivated or weakly activated arenes, including the electron-rich anisole, all reacted cleanly to give the corresponding 1,2,2-triarylethanones (**3c**,**e**,**f** and **3h**−**q**) (entries 3, 5−6, and 8−17, Table 1) in consistently good yields (46−71%). It may be noted that in the case of anisole and naphthalene 2 equiv of each of the arenes is required. The reaction with naphthalene, though it is a solid, proceeded without the need of any solvent in the presence of boron trifluoride etherate, which also provided the medium for the reaction. However, chlorobenzene afforded the product **3q** in 46% yield when the substrate is used

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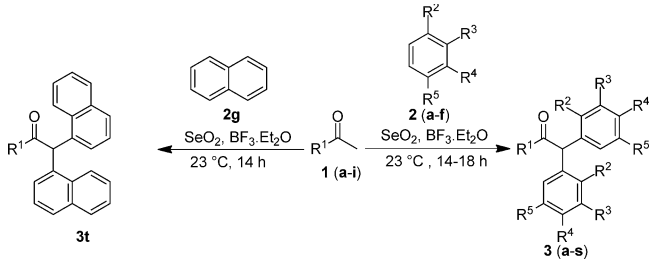
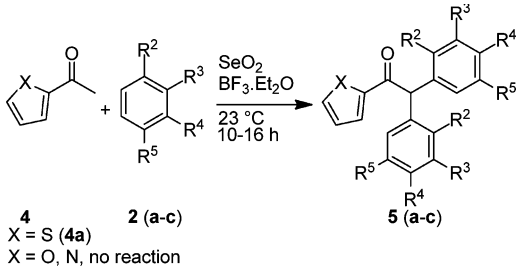
Table 1. Reaction of Substituted Acetophenones with Arenes in the Presence of SeO_2 and $BF_3{\cdot}Et_2O$[a]



entry	substrate **1** (R^1)	substrate **2** (R^2, R^3, R^4, R^5)	product **3**	yield (%)[c]
1	**1a**; R^1 = 4-ClC_6H_4	**2a**; R^2 = R^3 = R^4 = R^5 = H	**3a**	60
2	**1b**; R^1 = 4-$CH_3C_6H_4$	**2a**	**3b**	58
3	**1c**; R^1 = 4-BrC_6H_4	**2a**	**3c**	61
4	**1d**; R^1 = 3-$NO_2C_6H_4$	**2a**	**3d**	65
5	**1e**; R^1 = 4-$NO_2C_6H_4$	**2a**	**3e**	68
6	**1f**; R^1 = 3-$CH_3OC_6H_4$	**2a**	**3f**	55
7	**1g**; R^1 = 4-$CH_3OC_6H_4$	**2a**	**3g**	57
8	**1c**	**2b**; R^2 = R^3 = R^5 = H, R^4 = CH_3	**3h**[b]	63
9	**1d**	**2b**	**3i**[b]	70
10	**1e**	**2b**	**3j**[b]	69
11	**1b**	**2c**; R^2 = R^5 = H, R^3 = R^4 = CH_3	**3k**	59
12	**1c**	**2c**	**3l**	65
13	**1e**	**2c**	**3m**	71
14	**1h**; R^1 = 2-$CH_3OC_6H_4$	**2d**; R^3 = R^4 = H, R^2 = R^5 = CH_3	**3n**	57
15	**1e**	**2d**	**3o**	63
16	**1a**	**2e**; R^2 = R^3 = R^5 = H, R^4 = OCH_3	**3p**	69
17	**1e**	**2f**; R^2 = R^3 = R^5 = H, R^4 = Cl	**3q**	46
18	**1i**; 2-naphthyl	**2b**	**3r**[b]	41
19	**1i**	**2d**	**3s**	39
20	**1a**	**2g**	**3t**	58

[a]Reaction conditions: (i) substrate **1** (10 mmol), substrate **2a**–**d** (16 mL), SeO_2 (10 mmol), $BF_3{\cdot}Et_2O$ (49%, 6–7 mL), 0–23 °C, 14–18 h. (ii) Same as (i) except for the arene **2e** (20 mmol), **2f** (80 mmol), and **2g** (20 mmol) were used. [b]Combined yields of *ortho* and *para* isomer. [c]Isolated yields.

Table 2. Reaction of Heteroaryl Ketones with Benzene and Substituted Benzenes in the Presence of SeO_2 and $BF_3{\cdot}Et_2O$[a]



entry	substrate **4**	substrate **2** (R^2, R^3, R^4, R^5)	product **5**	yield (%)[b]
1	**4a**	**2a**	**5a**	65
2	**4a**	**2b**	**5b**	61
3	**4a**	**2c**	**5c**	58

[a]Reaction conditions are same as (i) in Table 1. [b]Isolated yields.

in excess (entry 17, Table 1). This is presumably because chlorobenzene exhibits decreased susceptibility to attack by the electrophiles. The reaction with acetanilide and nitrobenzene, however, gave only an intractible mixture. The scope of the reaction was further investigated with extended aromatic systems when it was found that, irrespective of whether the extended aromatic ring is on the ketones or the arylating substrate, diarylation takes place under the same reaction conditions (products **3r**–**t**, entries 18–20, Table 1).

To test the generality of the method, we extended our investigation to other aromatic ketones. Thus when 2-acetylthiophene (**4a**) was allowed to react with benzene (**2a**) in the presence of selenium dioxide and boron trifluoride etherate at room temperature for 18 h, a clean α,α-diarylation took place to afford 2,2-diphenyl-1-(thiophen-2-yl)ethanone (**5a**) (entry 1, Table 2) in 65% yield. In a similar fashion, **4a** reacted with substituted arenes **2b** and **2c** to give the corresponding products **5b** and **5c** in good yields. However, the reaction with heteroaryl ketones containing oxygen or

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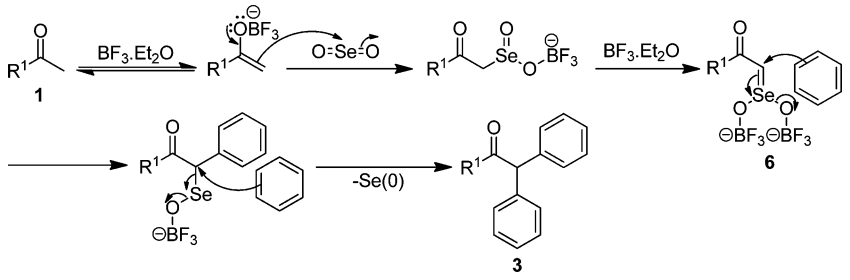
Scheme 1. Probable Mechanism for α,α-Diarylation



nitrogen failed to give the diarylated products (Table 2). Similarly, reactions with acetophenones already substituted at the α-carbon atom, such as propiophenone, do not give the expected monoarylated ketones.

Notably, the same procedure was followed in all of the reactions, and except for maintaining dry conditions, no other precautions were taken. The commercial reagents were used directly as received.

A probable mechanism for this reaction may be depicted as in Scheme 1. Enolization of the ketone (**1**) in the presence of boron trifluoride etherate is the first step followed by reaction with selenium dioxide to generate the intermediate **6**. The propensity of the selenium dioxide to get reduced to its zero valency state is evidently the driving force behind the umpolung arylation process[12] resulting in a facile nucleophilic attack on the α-carbon atom leading to the formation of the product **3** (Scheme 1). It may be noted that the proposed mechanism bears a strong similarity to that proposed by Moriarty et al., where the intermediate **6** behaves like the electrophile $C_6H_5I^+$-OB^-F_3 in the α-methoxylation reactions by the hypervalent iodine oxidation of silyl enol ethers.[13] Further, the participation of the intermediate **6** appears to be reasonable because, in all of the reactions, at no instance was the formation of 2-aryl-2-oxo-acetaldehyde observed.[14] We thus feel that the proposed mechanism is quite plausible.

In summary, we have reported a highly regioselective, first direct double arylation of the α-carbon atom of aromatic ketones without the use of expensive catalyst, thereby providing a valuable addition to the existing triarylation methods.[15] To our knowledge, this is also the first report of a C−C bond formation via the use of SeO_2 as an intermediary. Ongoing efforts are directed toward a detailed investigation on the reaction of α-substituted aromatic ketones with selenium dioxide in the presence of a Lewis acid which, as reported above, did not give the expected product and also attempts at selective monoarylation of aromatic ketones.[16]

EXPERIMENTAL SECTION

General Procedure. A stirring mixture of the aryl or heteroaryl methyl ketones (**1** or **4**) (10.0 mmol), selenium dioxide (10.0 mmol), and arenes (**2a−d**) (16 mL) was cooled in an ice-salt mixture. $BF_3{\cdot}Et_2O$ (49%, 7 mL) was then added dropwise over a period of 10 min, and the reaction mixture was allowed to stir at room temperature for 14−18 h. The reaction mixture was quenched with water (20 mL) and the red precipitate of selenium filtered off. The filtrate was extracted with diethyl ether (2 × 20 mL), and the combined organic extracts were washed with concentrated aqueous bicarbonate solution (1 × 20 mL) followed by brine (1 × 10 mL). The organic extract was dried over anhydrous Na_2SO_4 and concentrated. The triarylethanone was purified by column chromatography on silica gel.

Arenes such as chlorobenzene (8 equiv), anisole (2 equiv), and naphthalene (2 equiv) were used in the reaction.

1-(4-Chlorophenyl)-2,2-diphenylethanone [3a, Table 1].[10,11] Prepared from 1-(4-chlorophenyl)ethanone (1.30 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 6 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.9:0.1−9.3:0.3; hexane/ethylacetate. The product obtained after column chromatography was further recrystallized from dichloromethane and hexane 9:1. The product was isolated as light yellow crystals (1.85 g, 60% yield): mp 87−89 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.4 Hz, 2H), 7.36−7.24 (m, 12H), 5.96 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.0, 139.5, 138.7, 135.0, 130.4, 129.1, 128.9, 128.8, 127.3, 59.5; IR (KBr) 3093, 3067, 2924, 2853, 1668 cm^{-1}. Anal. Calcd for $C_{20}H_{15}ClO$: C, 78.30; H, 4.93. Found: C, 78.17; H, 4.89.

2,2-Diphenyl-1-(*p*-tolyl)ethanone [3b, Table 1].[11] Prepared from 1-(*p*-tolyl)ethanone (1.34 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 6 mL), and dry benzene (14 mL) following the general procedure in 18 h. Solvent system for column chromatography: 10.0:0.0−9.0:1.0; hexane/ethylacetate. The product was isolated as light yellow solid (1.67 g, 58% yield): mp 105−107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.0 Hz, 2H), 7.37−7.21 (m, 12H), 6.04 (s, 1H), 2.38 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.8, 143.9, 139.2, 134.3, 129.3, 129.2, 129.1, 128.7, 127.1, 59.3, 21.6; IR (KBr) 2924, 2855, 1675 cm^{-1}. Anal. Calcd for $C_{21}H_{18}O$: C, 88.08; H, 6.34. Found: C, 88.11; H, 6.29.

1-(4-Bromophenyl)-2,2-diphenylethanone [3c, Table 1].[11] Prepared from 1-(4-bromophenyl)ethanone (1.99 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 6 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.9:0.1−9.3:0.3; hexane/ethylacetate. The product was isolated as off white solid (2.15 g, 61% yield): mp 104−106 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 8.4 Hz, 2H), 7.47 (d, J = 8.4 Hz, 2H), 7.30−7.16 (m, 10H), 5.88 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.2, 138.7, 135.4, 132.0, 130.5, 129.1, 128.8, 128.3, 127.3, 59.5; IR (KBr) 3062, 3024, 2923, 1678 cm^{-1}. Anal. Calcd for $C_{20}H_{15}BrO$: C, 68.39; H, 4.30. Found: C, 68.47; H, 4.28.

1-(3-Nitrophenyl)-2,2-diphenylethanone [3d, Table 1]. Prepared from 1-(3-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol) $BF_3{\cdot}Et_2O$ (49%, 6 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.5:0.1−9.0:1.0; hexane/ethylacetate. The product obtained after column chromatography was further recrystallized from dichloromethane and hexane 9:2. The product was isolated as light yellow crystals (2.07 g, 65% yield): mp 121−123 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.74 (m, 1H), 8.29−8.22 (m, 2H), 7.53 (t, J = 8.0 Hz, 1H), 7.29−7.18 (m, 10H), 5.94 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.0, 147.9, 138.0, 134.5, 130.1, 129.9, 129.1, 129.0, 127.6, 127.3, 123.8, 59.9; IR (KBr) 3079, 2920, 1693, 1529 cm^{-1}. Anal. Calcd for $C_{20}H_{15}NO_3$: C, 75.70; H, 4.76; N, 4.41. Found: C, 75.68; H, 4.72; N, 4.43.

1-(4-Nitrophenyl)-2,2-diphenylethanone [3e, Table 1]. Prepared from 1-(4-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.5:0.1−9.0:1.0; hexane/ethylacetate. The product was isolated as light yellow crystals (2.16 g, 68% yield): mp 152−154 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (d, J = 8.8 Hz, 2H),

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8.10 (d, J = 8.8 Hz, 2H) 7.35−7.24 (m, 10H), 6.00 (s, 1H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 196.8, 150.1, 141.2, 138.1, 130.0, 129.1, 129.0, 127.6, 123.9, 60.2; IR (KBr) 3112, 3056, 3025, 2938, 2858, 1692, 1523 cm^{-1}. Anal. Calcd for $C_{20}H_{15}NO_3$: C, 75.70; H, 4.76; N, 4.41. Found: C, 75.82; H, 4.73; N, 4.42.

1-(3-Methoxyphenyl)-2,2-diphenylethanone [3f, Table 1].[11] Prepared from 1-(3-methoxyphenyl)ethanone (1.37 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.8:0.2−9.6:0.4; hexane/ethylacetate. The product was isolated as off white solid (1.67 g, 55% yield): mp 106−108 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (d, J = 7.6 Hz, 1H), 7.46 (s, 1H,) 7.27−7.16 (m, 11H), 6.98 (dd, J = 2.0 Hz, 8.0 Hz, 1H), 5.95 (s, 1H), 3.73 (s, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 198.1, 159.8, 139.1, 138.2, 129.6, 129.1, 128.7, 127.2, 121.6, 119.5, 113.3, 59.6, 55.4; IR (KBr) 3076, 3024, 2924, 2853, 1676 cm^{-1}. Anal. Calcd for $C_{21}H_{18}O_2$: C, 83.42; H, 6.00. Found: C, 83.44; H, 5.94.

1-(4-Methoxyphenyl)-2,2-diphenylethanone [3g, Table 1]. Prepared from 1-(4-methoxyphenyl)ethanone (1.50 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 6 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.8:0.2−9.6:0.4; hexane/ethylacetate. The product was isolated as white solid (1.73 g, 57% yield): mp 105−107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (d, J = 8.8 Hz, 2H), 7.26−7.15 (m, 10H), 6.80 (d, J = 8.8 Hz, 2H), 5.92 (s, 1H), 3.75 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.7, 163.4, 139.4, 131.3, 130.6, 129.2, 128.7, 127.0, 59.1, 55.5; IR (KBr) 3059, 3028, 2923, 2847, 1673, 1260, 1023 cm^{-1}. Anal. Calcd for $C_{21}H_{18}O_2$: C, 83.42; H, 6.00. Found: C, 83.33; H, 5.95.

1-(4-Bromophenyl)-2,2-di-*p*-tolylethanone [3h, Table 1]. Prepared from 1-(4-bromophenyl)ethanone (1.99 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and dry toluene (16 mL) following the general procedure in 16 h. Solvent system for column chromatography: 9.8:0.2−9.6:0.4; hexane/ethylacetate. The product was isolated as off white solid (2.39 g, 63% yield): mp 127−130 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, J = 8.4 Hz, 2H), 7.42 (d, J = 8.4 Hz, 2H), 7.03 (m, 8H), 5.79 (s, 1H), 2.21 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 136.9, 135.9, 135.6, 131.9, 130.6, 129.6, 129.5, 128.9, 58.9, 21.1; IR (KBr) 3088, 3057, 3024, 2917, 2860, 1685 cm^{-1}. Anal. Calcd for $C_{22}H_{19}BrO$: C, 69.67; H, 5.05. Found: C, 69.86; H, 4.93.

1-(3-Nitrophenyl)-2,2-di-*p*-tolylethanone [3i, Table 1]. Prepared from 1-(3-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and dry toluene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.5:0.5−8.8:1.2; hexane/ethylacetate. The product was isolated off white crystalline solid (2.42 g, 70% yield): mp 125−127 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.74 (s, 1H), 8.27 (d, J = 8.0 Hz, 1H), 8.22 (d, J = 8.0 Hz, 1H), 7.52 (t, J = 8.0 Hz, 1H), 7.08 (m, 8H), 5.87 (s, 1H), 2.24 (s, 6H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 196.3, 148.4, 137.2, 135.2, 134.5, 129.9, 129.7, 129.5, 128.9, 127.2, 123.8, 59.2, 21.1; IR (KBr) 3085, 3026, 2919, 2868, 1694, 1526 cm^{-1}. Anal. Calcd for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.52; H, 5.50; N, 4.10.

1-(4-Nitrophenyl)-2,2-di-*p*-tolylethanone [3j, Table 1]. Prepared from 1-(4-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and dry toluene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.5:0.5−9.0:1.0; hexane/ethylacetate. The product was isolated as yellow solid (2.39 g, 69% yield): mp 142−144 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (d, J = 8.8 Hz, 2H), 8.03 (d, J = 8.8 Hz, 2H), 7.08−7.00 (m, 8H), 5.83 (s, 1H), 2.24 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.1, 150.0, 141.4, 137.3, 135.2, 130.0, 129.7, 128.9, 123.8, 59.6, 21.1; IR (KBr) 3102, 3073, 2921, 2856, 1692, 1529 cm^{-1}. Anal. Calcd for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.43; H, 5.61; N, 4.15.

2,2-Bis(3,4-dimethylphenyl)-1-(*p*-tolyl)ethanone [3k, Table 1]. Prepared from 1-(*p*-tolyl)ethanone (1.34 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and *o*-xylene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 10.0:0.0−9.0:1.0; hexane/ethylacetate. The product was isolated as white solid (2.03 g, 59% yield): mp 108−110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83 (d, J = 8.0 Hz, 2H), 7.12 (d, J = 8.0 Hz, 2H), 7.00−6.96 (m, 4H), 6.92−6.90 (m, 2H), 5.82 (s, 1H), 2.29 (s, 3H), 2.13 (s, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.3, 143.6, 136.9, 136.8, 135.3, 134.5, 130.3, 130.0, 129.2, 129.1, 126.4, 58.7, 21.6, 19.9, 19.4; IR (KBr) 3014, 2970, 2920, 1670 cm^{-1}. Anal. Calcd for $C_{25}H_{26}O$: C, 87.68; H, 7.65. Found: C, 87.71; H, 7.62.

1-(4-Bromophenyl)-2,2-bis(3,4-dimethylphenyl)ethanone [3l, Table 1]. Prepared from 1-(4-bromophenyl)ethanone (1.99 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and distilled *o*-xylene (16 mL) following the general procedure in 16 h. Solvent system for column chromatography: 9.9:0.1−9.6:0.4; hexane/ethylacetate. The product was isolated as off white solid (2.65 g, 65% yield): mp 107−109 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78−7.76 (m, 2H), 7.46−7.44 (m, 2H), 7.00 (d, J = 7.6 Hz, 2H), 6.93 (s, 2H), 6.88 (d, J = 7.6 Hz, 2H), 5.75 (s, 1H), 2.13 (s, 12H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 197.7, 137.0, 136.3, 135.6, 135.5, 131.8, 130.4, 130.2, 130.0, 128.0, 126.4, 58.9, 19.9, 19.4; IR (KBr) 3060, 2936, 2845, 1670 cm^{-1}. Anal. Calcd for $C_{24}H_{23}BrO$: C, 70.77; H, 5.69. Found: C, 70.79; H, 5.66.

2,2-Bis(3,4-dimethylphenyl)-1-(4-nitrophenyl)ethanone [3m, Table 1]. Prepared from 1-(4-nitrophenyl)ethanone (1.11 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and distilled *o*-xylene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.5:0.5−8.9:1.1; hexane/ethylacetate. The product was isolated as yellow solid (2.66 g, 71% yield): mp 121−123 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (d, J = 8.8 Hz, 2H), 8.13 (d, J = 8.8 Hz, 2H), 7.11 (d, J = 7.6 Hz, 2H), 7.04 (s, 2H), 6.99−6.97 (m, 2H), 5.87 (s, 1H), 2.24 (s, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.2, 150.0, 141.5, 137.2, 135.9, 135.6, 130.2, 130.2, 130.0, 126.4, 123.8, 59.7, 19.9, 19.4; IR (KBr) 3101, 3069, 2921, 2856, 1694, 1524 cm^{-1}. Anal. Calcd for $C_{24}H_{23}NO_3$: C, 77.19; H, 6.21; N, 3.75. Found: C, 77.23; H, 6.16; N, 3.76.

2,2-Bis(2,5-dimethylphenyl)-1-(2-methoxyphenyl)ethanone [3n, Table 1]. Prepared from 1-(2-methoxyphenyl)ethanone (1.34 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and distilled *p*-xylene (16 mL) following the general procedure in 16 h. Solvent system for column chromatography: 9.8:0.2−9.7:0.3; hexane/ethylacetate. The product was isolated as off white solid (2.05 g, 57% yield): mp 122−124 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.72 (dd, J = 1.6 Hz, 7.6 Hz, 1H), 7.30−7.26 (m, 1H), 6.98−6.66 (m, 8H), 6.36 (s, 1H), 3.63 (s, 3H), 2.12 (s, 6H), 2.11(s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.5, 158.3, 137.2, 135.1, 133.5, 133.4, 131.6, 130.2, 130.0, 128.4, 127.5, 120.8, 111.9, 57.2, 55.5, 21.2, 19.5; IR (KBr) 2942, 2917, 2867, 1682, 1246, 1023 cm^{-1}. Anal. Calcd for $C_{25}H_{26}O_2$: C, 83.76; H, 7.31. Found: C, 83.53; H, 7.39.

2,2-Bis(2,5-dimethylphenyl)-1-(4-nitrophenyl)ethanone [3o, Table 1]. Prepared from 1-(4-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), $BF_3{\cdot}Et_2O$ (49%, 7 mL), and distilled *p*-xylene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.5:0.5−8.9:1.1; hexane/ethylacetate. The product was isolated as light yellow solid (2.36 g, 63% yield): mp 151−153 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (d, J = 8.8 Hz, 2H), 8.01 (d, J = 8.8 Hz, 2H), 7.14 (d, J = 7.6 Hz, 2H), 7.03 (d, J = 7.6 Hz, 2H), 6.67 (s, 2H), 6.11 (s, 1H), 2.22 (s, 12H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 197.9, 150.1, 141.4, 135.9, 135.5, 132.7, 130.8, 129.8, 129.6, 128.4, 124.0, 54.2, 21.2, 19.4; IR (KBr) 3108, 3080, 3026, 2971, 2943, 2918, 2863, 1686, 1520 cm^{-1}. Anal. Calcd for $C_{24}H_{23}NO_3$: C, 77.19; H, 6.21; N, 3.75. Found: C, 77.21; H, 6.18; N, 3.76.

1-(4-Chlorophenyl)-2,2-bis(4-methoxyphenyl)ethanone [3p, Table 1]. 1-(4-Chlorophenyl)ethanone (1.30 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol) $BF_3{\cdot}Et_2O$ (49%, 7 mL), and anisole (2.16 g, 20 mmol) following the general procedure in 14 h. Solvent system for column chromatography: 9.8:0.2−8.0:2.0; hexane/ethylacetate. The product was isolated as yellow viscous liquid (2.53 g, 69% yield): mp 120−122 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, J = 8.4 Hz, 2H), 7.19 (d, J = 8.4 Hz, 2H), 7.02 (d, J = 8.8 Hz, 4H),

6.72 (d, J = 8.4 Hz, 4H), 5.75 (s, 1H), 3.59 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 158.7, 139.3, 135.1, 131.2, 130.4, 130.1, 128.9, 114.3, 57.9, 55.2; IR (KBr) 3005, 2952, 2839, 1686, 1600, 1507, 1460, 1248, 1182 cm^{-1}; MS (ES+) calcd for $C_{22}H_{19}ClO_3$ 366.10, found m/z 389.0 [M + Na]$^+$. Anal. Calcd for $C_{22}H_{19}ClO_3$: C, 72.03; H, 5.22; Found: C, 72.16; H, 5.20.

2,2-Bis(4-chlorophenyl)-1-(4-nitrophenyl)ethanone [3q, Table 1]. Prepared from 1-(4-nitrophenyl)ethanone (1.65 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), BF_3·Et_2O (49%, 7 mL), and chlorobenzene (8.13 mL, 80 mmol) following the general procedure in 16 h. Solvent system for column chromatography: 9.8:0.2−8.5:1.5; hexane/ethylacetate. The product was isolated as off white solid (1.78 g, 46% yield): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (d, J = 8.8 Hz, 2H), 8.02 (d, J = 8.8 Hz, 2H), 7.25 (d, J = 8.4 Hz, 4H), 7.09 (d, J = 8.4 Hz, 4H), 5.85 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.0, 150.3, 140.7, 136.1, 133.9, 130.3, 129.9, 129.3, 124.0, 58.7; IR (KBr) 3103, 3073, 2925, 2855, 1695, 1530 cm^{-1}. Anal. Calcd for $C_{20}H_{13}Cl_2NO_3$: C, 62.19; H, 3.39; N, 3.63. Found: C, 62.08; H, 3.33; N, 3.70.

1-(Naphthalen-2-yl)-2,2-di-*p*-tolylethanone [3r, Table 1]. Prepared from 1-(naphthalen-2-yl)ethanone (1.70 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol) BF_3.Et_2O (49%, 7 mL) and dry toluene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.9:0.1−9.5:0.5; hexane/ethylacetate. The product obtained after column chromatography was further washed with *n*-pentane to give a light yellow solid (1.44 g, 41% yield): mp 114−116 °C ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.52 (s, 1H), 8.06−7.45 (m, 6H), 7.20 (d, J = 8.0 Hz, 4H), 7.12 (d, J = 8.0 Hz, 4H) 6.13 (s, 1H), 2.29 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.5, 136.7, 136.4, 135.4, 134.2, 132.4, 130.6, 129.7, 129.4, 129.0, 128.4, 128.4, 127.7, 126.6, 124.7, 58.7, 21.0; IR (KBr) 3435, 3019, 2920, 2864, 1670, 1498, 1464 cm^{-1}. Anal. Calcd for $C_{26}H_{22}O$: C, 89.11; H, 6.33. Found: C, 89.16; H, 6.40.

2,2-Bis(2,5-dimethylphenyl)-1-(naphthalen-2-yl)ethanone [3s, Table 1]. Prepared from 1-(naphthalen-2-yl)ethanone (1.70 g, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol) BF_3·Et_2O (49%, 7 mL), and *p*-xylene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.9:0.1−9.5:0.5; hexane/ethylacetate. The product obtained after column chromatography was further washed with *n*-pentane to give a light yellow (1.48 g, 39% yield); mp 155−157 °C ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (s, 1H), 7.98−7.77 (m, 4H), 7.55−7.46 (m, 2H), 7.12 (d, J = 7.6 Hz, 2H), 6.99 (d, J = 7.6 Hz, 2H), 6.79 (s, 2H), 6.34 (s, 1H), 2.26 (s, 6H) 2.20 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.4, 136.7, 135.7, 135.5, 134.4, 132.8, 132.6, 130.6, 130.2, 130.0, 129.8, 128.6, 128.5, 128.0, 127.7, 126.7, 124.5, 53.7, 21.2, 19.6; IR (KBr) 3432, 3044, 3020, 2923, 2856, 1674, 1511, 1466, 1277 cm^{-1}; MS (ES+) calcd for $C_{28}H_{26}O$ 378.2, found m/z 401.4 [M + Na]$^+$. Anal. Calcd for $C_{28}H_{26}O$: C, 88.85; H, 6.92. Found: C, 88.91; H, 6.81.

1-(4-Chlorophenyl)-2,2-di(naphthalen-1-yl)ethanone [3t, Table 1]. Prepared from 1-(4-chlorophenyl)ethanone (1.30 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol) BF_3 ·Et_2O (49%, 7 mL), and naphthalene (2.56 g, 20 mmol) following the general procedure in 14 h. Solvent system for column chromatography: 9.5:0.5 hexane/ethylacetate. The product obtained after column chromatography was further washed with *n*-pentane to give a light yellow solid (2.36 g, 58% yield): mp 220−223 °C ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97−7.00 (m, 8H), 7.51−7.11(m, 11H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 139.7, 134.3, 134.2, 131.4, 131.4, 130.4, 130.3, 129.5, 129.3, 129.2, 128.4, 127.9, 125.9, 125.6, 122.9, 52.1; IR (KBr) 3445, 3053, 2922, 2853, 1689, 1587, 1570, 1397, 1310, 1290, 1203 cm^{-1}; LC-MS calcd for $C_{22}H_{19}ClO_3$ 406.1, found m/z 407.2 [M + H]$^+$. Anal. Calcd for $C_{28}H_{19}ClO$: C, 82.65; H, 4.71. Found: C, 82.79; H, 4.60.

2,2-Diphenyl-1-(thiophen-2-yl)ethanone [5a, Table 2]. Prepared from 1-(thiophen-2-yl)ethanone (1.08 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), BF_3·Et_2O (49%, 7 mL), and dry benzene (16 mL) following the general procedure in 18 h. Solvent system for column chromatography: 9.8:0.2−9.5:0.5; hexane/ethylacetate. The product was isolated as white solid (1.81 g, 65% yield): mp 140−143 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.66 (d, J = 3.6 Hz, 1H), 7.50 (d, J = 4.4 Hz, 1H) 7.24−7.15 (m, 10H), 6.97 (t, J = 4.0 Hz, 1H), 5.79 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.1, 144.2, 138.8, 134.2, 132.9, 129.1, 128.8, 128.5, 127.3, 60.5; IR (KBr) 3112, 3090, 2925, 1651 cm^{-1}. Anal. Calcd for $C_{18}H_{14}OS$: C, 77.66; H, 5.07; S, 11.52; H. Found: C, 77.86; H, 5.15; S, 11.47.

1-(Thiophen-2-yl)-2,2-di-*p*-tolylethanone [5b, Table 2]. Prepared from 1-(thiophen-2-yl)ethanone (1.08 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), BF_3·Et_2O (49%, 7 mL), and dry toluene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.8:0.2−9.5:0.5; hexane/ethylacetate. The product was isolated as off white solid (1.87 g, 61% yield): mp 131−133 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (d, J = 3.6 Hz, 1H), 7.49 (d, J = 4.8 Hz, 1H), 7.12−7.03 (m, 8H), 6.96 (t, J = 4.0 Hz, 1H), 5.72 (s, 1H), 2.22 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.4, 144.3, 136.8, 136.1, 133.9, 132.7, 129.4, 128.9, 128.2, 59.8, 21.1; IR (KBr) 3085, 3018, 2919, 2858, 1647 cm^{-1}. Anal. Calcd for $C_{20}H_{18}OS$: C, 78.39; H, 5.92; S, 10.46. Found: C, 78.53; H, 5.87; S, 10.33.

2,2-Bis(3,4-dimethylphenyl)-1-(thiophen-2-yl)ethanone [5c, Table 2]. Prepared from 1-(thiophen-2-yl)ethanone (1.08 mL, 10.0 mmol), selenium dioxide (1.11 g, 10.0 mmol), BF_3·Et_2O (49%, 7 mL), and distilled *o*-xylene (16 mL) following the general procedure in 14 h. Solvent system for column chromatography: 9.8:0.2−9.7:0.3; hexane/ethylacetate. The product was isolated as white solid (1.94 g, 58% yield): mp 73−75 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74 (d, J = 3.6 Hz, 1H), 7.58 (d, J = 4.8 Hz, 1H), 7.08−7.00 (m, 7H), 5.75 (s, 1H), 2.21 (s, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.6, 144.4, 136.9, 136.4, 135.5, 133.9, 132.7, 130.2, 129.9, 128.2, 126.4, 59.9, 19.9, 19.4; IR (KBr) 2923, 2855, 1654 cm^{-1}. Anal. Calcd for $C_{22}H_{22}OS$: C, 79.00; H, 6.63; S, 9.59. Found: C, 79.21; H, 6.58; S, 9.50.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Figures giving ^{1}H NMR and ^{13}C NMR spectra compounds and details of the X-ray diffraction analysis (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

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■ REFERENCES

(1) (a) Prim, D.; Campagne, J.-M.; Joseph, D.; Andrioletti, B. *Tetrahedron* **2002**, *58*, 2041−2075. (b) Miura, M.; Nomura, M. *Top. Curr. Chem.* **2002**, *219*, 211−241. (c) Culkin, D. A.; Hartwig, J. F. *Acc. Chem. Res.* **2003**, *36*, 234−245.

(2) (a) Piers, E.; Oballa, R. M. *Tetrahedron Lett.* **1995**, *36*, 5837−5860. (b) Ryan, J. H.; Stang, P. J. *Tetrahedron Lett.* **1997**, *38*, 5061−5064. (c) Muratake, H.; Hayakawa, A.; Natsume, M. *Chem. Pharm Bull.* **2000**, *48*, 1558−1566. (d) Fox, J. M.; Huang, X.; Chieffi, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2000**, *122*, 1360−1370, and references included therein. (e) Deng, H. B.; Konopelski, J. P. *Org. Lett.* **2001**, *3*, 3001−3004.

(3) (a) Palucki, M.; Buchwald, S. L. *J. Am. Chem. Soc.* **1997**, *119*, 11108−11109. (b) Old, D. W.; Wolfe, J. P.; Buchwald, S. L. *J. Am. Chem. Soc.* **1998**, *120*, 9722−9723. (c) Moradi, W. A.; Buchwald, S. L. *J. Am. Chem. Soc.* **2001**, *123*, 7996−8002.

(4) (a) Churruca, F. R.; Martin, S.; Tellitu, I.; Dominguez, E. *Org. Lett.* **2002**, *4*, 1591−1594. (b) Churruca, F. R.; Martin, S.; Tellitu, I.; Dominguez, E. *Tetrahedron Lett.* **2003**, *44*, 5925−5929. (c) Churruca,

F. R.; Martin, S.; Carril, M.; Tellitu, I.; Dominguez, E. *Tetrahedron* **2004**, *60*, 2393−2408. (d) Churruca, F. R.; Martin, S.; Tellitu, I.; Dominguez, E. *Tetrahedron Lett.* **2006**, *47*, 3233−3237.
(5) Kawatsura, M.; Hartwig, J. F. *J. Am. Chem. Soc.* **1999**, *121*, 1473−1478.
(6) Satoh, T.; Kametani, Y.; Terao, Y.; Miura, M.; Nomura, M. *Tetrahedron Lett.* **1999**, *40*, 5345−5348.
(7) Bellina, F.; Rossi, R. *Chem. Rev.* **2010**, *110*, 1082−1146.
(8) Myrboh, B.; Ila, H.; Junjappa, H. *Synthesis* **1981**, 126−127.
(9) (a) Ashley, M. R. L.; Nantz, M. H. *Tetrahedron Lett.* **2000**, *41*, 3295−3298. (b) Valliant, J. F.; Schaffer, P.; Stephenson, K. A.; Britten, J. F. *J. Org. Chem.* **2002**, *67*, 383−387. (c) Ernst, T.; Chang, L.; Cooray, D.; Salvador, C.; Jovocich, J.; Walot, I.; Boone, K.; Chlebowski, R. *J. Natl. Cancer Inst.* **2002**, *94*, 592−597.
(10) Zhou, L.; Zhang, Y. *Tetrahedron* **2000**, *56*, 2953−2960.
(11) Padmanaban, M.; Biju, A. T.; Glorius, F. *Org. Lett.* **2011**, *13*, 98−101.
(12) Lundin, P. M.; Esquivias, J.; Fu, G. C. *Angew. Chem., Int. Ed.* **2009**, *48*, 154−156.
(13) Moriarty, R. M.; Prakash, M.; Duncan, M. P.; Vaid, R. K. *J. Org. Chem.* **1987**, *52*, 150−153.
(14) (a) Riley and Gray *Organic Syntheses*; John Wiley and Sons: New York, 1935; Vol. *XV*, p 67. (b) Corey, E. J.; Schaefer, J. P. *J. Am. Chem. Soc.* **1960**, *82*, 918−929.
(15) (a) Heck, R. F. *Org. React.* **1982**, *27*, 345−390. (b) de Meijere, A.; Meyer, F. E. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 2379−2411. (c) Cabri, W.; Candiani, I. *Acc. Chem. Res.* **1995**, *28*, 2−7. (d) Beletskaya, I. P.; Cheprakov, A. V. *Chem. Rev.* **2000**, *100*, 3009−3066. (e) Nilsson, P.; Larhed, M.; Hallberg, A. *J. Am. Chem. Soc.* **2001**, *123*, 8217−8225.
(16) A detailed investigation is in progress and the result will be communicated subsequently.