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# Palladium(II)-Catalyzed Transformation of 3-Alkylbenzofurans to [2,3′-Bibenzofuran]-2′(3′H)-ones: Oxidative Dimerization of 3-Alkylbenzofurans

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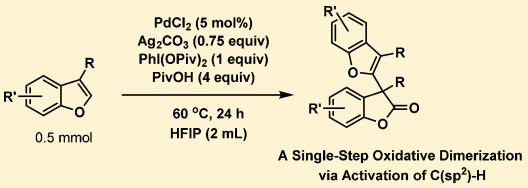
Supporting Information

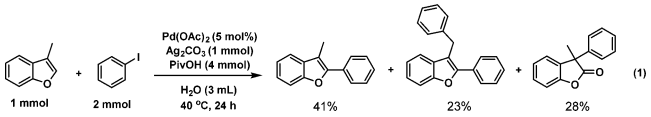
**ABSTRACT:** An unprecedented oxidative dimerization by palladium catalysis has been developed using $PhI(OPiv)_2$ as a by-standing oxidant. This provides a facile method for the synthesis of quaternary 2,3′-bibenzofuran-2′(3′)-ones from readily accessible substrates. A plausible mechanism involving a Pd(II)−Pd(IV) catalytic cycle is proposed; a trace amount of water is required for subsequent oxidation.



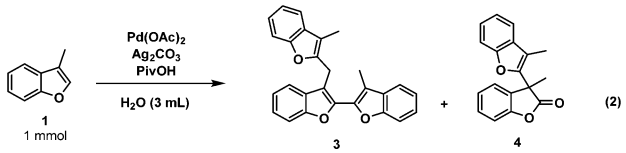

Recently, Pd-catalyzed C−H functionalization has been extensively studied as a powerful and versatile tool in organic synthesis.[1] Such processes generally proceed through a Pd(0)−Pd(II) catalytic cycle. However, based on experimental and theoretical studies, catalytic reactions involving a Pd(II)−Pd(IV) cycle have been proposed[1e,2] as an alternative. These recently attracted great interest in synthetic chemistry.[3] Because of the unique reactivity of Pd(IV) complexes,[4] Pd(II)−Pd(IV) catalysis should exhibit complementary reactivity and selectivity relative to analogous transformations by Pd(0)−Pd(II) catalysis.

The 3,3′-biindole scaffolds are important subunits in many natural products, and in the synthetic world.[6] Thus, many useful methods for the construction of biindols have been developed.[7] Conversely, very few studies on the chemistry and synthesis of bibenzofurans have been reported[8] to date even though several bibenzofuran derivatives exhibit biological activities, including the inhibition of propyl endopeptidase[9] and protein phosphatase 1B (PTP-1B),[10] antimicrobial effects,[11] and antiprotozoal activities.[12] Moreover, the benzofuran-2-one moiety is present in a large number of products of pharmacological interest and in natural products.[13] Therefore, it is highly desirable to develop a controlled method to synthesize bibenzofuran-2-ones from common starting materials.

Recently, we reported[5] a palladium-catalyzed bisarylation of 3-alkylbenzofurans in water to form 3-arylalkyl-2-arylbenzofurans. In the bisarylation reaction of 3-methylbenzofuran with iodobenzene in the presence of $Pd(OAc)_2$ (5 mol%), $Ag_2CO_3$ (1 mmol), and PivOH (4 mmol), 3-methyl-3-phenylbenzofuran-2(3H)-one was isolated as one of the major products (28% yield, eq 1).




The unexpected formation of benzofuran-2(3H)-one inspired us to investigate its formation in detail. During our study on the formation of benzofuran-2(3H)-one from 3-methylbenzofuran without the presence of iodobenzene, bibenzofuran-2-one was isolated as one of the major products. This dimeric compound is unprecedented. Therefore, we decided to study the formation of this dimeric benzofuranone from 3-methylbenzofuran. Herein, we communicate our preliminary data for the synthesis of bibenzofuran-2-ones from 3-alkylbenzofuranes. In this novel reaction, oxidative coupling via C−H activation of a $C(sp^2)$-H bond and oxidation to a ketone is achieved in a single step, and a Pd(II)−Pd(IV) catalytic cycle is proposed.




Initially, the self-reaction of 3-methylbenzofuran (**1**) under previously established bisarylation conditions ($Pd(OAc)_2$, $Ag_2CO_3$, and PivOH in water) afforded a mixture of two compounds, namely, bis-arylated (3-methyl-3′-((3-methylbenzofuran-2-yl)methyl)-2,2′bibenzofuran) (**3**), and oxidative dimerized (3,3′-dimethy;[2,3′-bibenzofuran]-2′(3′H)-one) (**4**) in 27 and 30% yields, respectively (eq 2). We therefore attempted to optimize the reaction conditions in the presence of a palladium catalyst (Table 1). The reaction solvents were screened first (see SI). When HFIP (1,1,1,3,3,3-hexafluoro-2-propanol) or TFE (2,2,2-trifluoroethanol) were used as the solvent, (2,3′-bibenzofuran)-2′(3′H)-one (**4**) was selectively formed;[14] relatively less decomposition was observed when the former solvent was used. Recently, Rao et al.[14a] reported a palladium-catalyzed oxidative coupling reaction for the synthesis of a 2,2′-difunctional biaryl in HFIP. They proposed that

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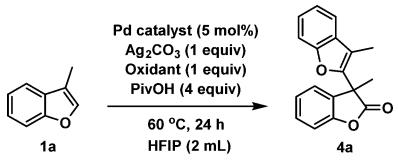
**Table 1. Optimization of the Reaction Conditions**[a]




| entry | catalyst | oxidant | yield[b] (%) |
|---|---|---|---|
| 1 | $Pd(OAc)_2$ | None | 32 |
| 2 | $Pd(OAc)_2$ | $PhI(OAc)_2$ | 58 |
| 3 | $Pd(OAc)_2$ | $PhI(OTFA)_2$ | 15 |
| 4 | $Pd(OAc)_2$ | $PhI(OPiv)_2$ | 64 |
| 5 | $Pd(OAc)_2$ | NFSI | 57 |
| 6 | $Pd(OAc)_2$ | $Cu(OAc)_2·H_2O$ | 62 |
| 7 | $Pd(OAc)_2$ | NCS | 28 |
| 8 | $Pd(OAc)_2$ | NBS | 3 |
| 9 | $PdCl_2$ | $PhI(OPiv)_2$ | 72 |
| 10 | $Pd(MeCN)_2Cl_2$ | $PhI(OPiv)_2$ | 21 |
| 11 | $Pd(PhCN)_2Cl_2$ | $PhI(OPiv)_2$ | 29 |
| **12**[c] | **$PdCl_2$** | **$PhI(OPiv)_2$** | **73** |

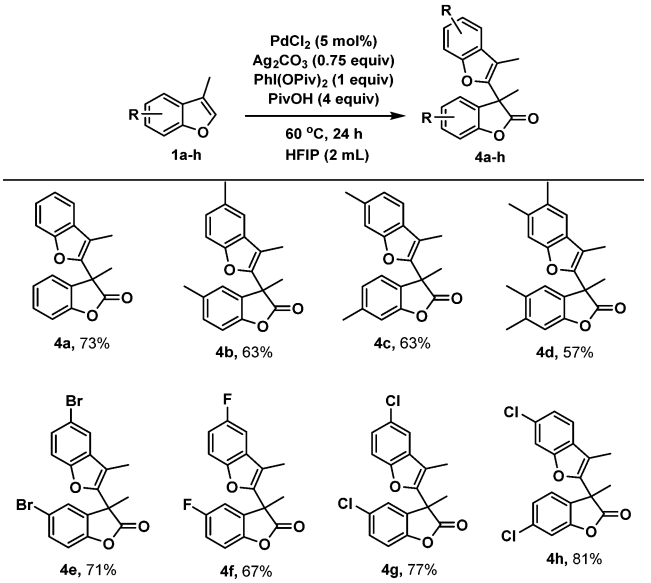
[a]Reaction conditions: **1a** (0.5 mmol), Pd catalyst (0.025 mmol, 5 mol %), $Ag_2CO_3$ (0.5 mmol, 1 equiv), oxidant (0.5 mmol, 1 equiv), PivOH (2 mmol, 4 equiv), HFIP (2 mL), 60 °C, 24 h. [b]Isolated yield. [c]0.75 equiv of $Ag_2CO_3$.

HFIP works as an effective ligand for palladium to promote the reaction. They discovered that the HFIP solvent and the oxidants are the critical factors in this oxidative coupling reaction. Larrosa et al.[14b] also proposed the role of HFIP as an effective ligand for palladium to form a palladium alkoxide. These species may be further stabilized by H-bonding with another HFIP molecule. However, even in the presence of HFIP, decomposition was not eliminated from our reactions. We next screened the reaction conditions, including the palladium catalyst and the oxidant; we postulated that the highly electrophilic palladium would favor the oxidative dimerization pathway.

A variety of oxidants were screened using $Pd(OAc)_2$ as a palladium catalyst. In the presence of an oxidant, a decrease in decomposition was observed. Moreover, oxidants, such as $PhI(OAc)_2$, $PhI(OPiv)_2$, NFSI (N-fluorobenzenesulfonimide), and $Cu(OAc)_2·H_2O$ (entries 2, 4, 5, and 6, respectively), afforded the furanone in reasonable to high yields (57−62%). However, in some cases, the use of $PhI(OTFA)_2$, NCS, and NBS as an oxidant was detrimental to the yield of the reaction (entries 3, 7, and 8, respectively: 3−28%). Other palladium catalyst, such as $PdCl_2$, $Pd(MeCN)_2Cl_2$, and $Pd(PhCN)_2Cl_2$, were applied; the best yield was observed in the presence of $PdCl_2$ and $PhI(OPiv)_2$ (entry 9). Notably, optimizations with $PdCl_2/PhI(OPiv)_2$ combination and <1 equiv of $Ag_2CO_3$, increased the yield to 73% (entries 9 and 12). Therefore, $PhI(OPiv)_2$ was chosen as a bystanding oxidant.[15] From these results, the optimum conditions were established as follows: 0.5 mmol 3-methylbenzofuran, 5 mol% $PdCl_2$, 0.75 equiv $Ag_2CO_3$, 1 equiv $PhI(OPiv)_2$, 4 equiv PivOH, 2 mL of HFIP, and a temperature of 60 °C for 24 h.

With the optimum reaction conditions in hand, we next investigated how substitution on the benzofuran ring affected the oxidative dimerization of the 3-methylbenzofurans (Scheme 1). We observed that under optimized reaction conditions various 3-methylbenzofurans bearing either electron-donating (Me) or electron-withdrawing (F, Cl, Br) groups on the 5- and/or 6-positions provided desired products **4a−h** in high

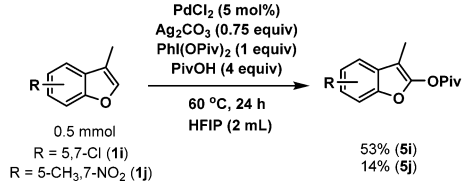
**Scheme 1. Substrate Scope for the Pd-Catalyzed Oxidative Dimerization of 3-Methylbenzofurans**[a]




[a]Reaction conditions: **1** (0.5 mmol), $PdCl_2$ (0.025 mmol, 5 mol%), $Ag_2CO_3$ (0.375 mmol, 0.75 equiv), $PhI(OPiv)_2$ (0.5 mmol, 1 equiv), PivOH (2 mmol, 4 equiv), HFIP (2 mL), 60 °C, 24 h. Yields are isolated yield.

yields. 3-Methylbenzofurans (**4g** and **4h**) having a chloro substituent on the 5- or 6-position of the benzene segment exhibited a higher yield than the derivatives (**4b** ∼ **4d**) with a methyl group on the 5- and/or 6-position of the benzene segment. Strangely, 6-methoxy-3-methylbenzofuran and 3-methylnaphtho[1,2-*b*]furan were decomposed under reaction conditions (not shown in here).

In the case of 5,7-dichloro-3-methylbenzofuran (**1i**) and 3,5-dimethyl-7-nitrobenzofuran (**1j**), the corresponding products were not isolated, but unexpectedly 5,7-dichloro-3-methylbenzofuran-2-yl pivalate (**5i**) and 3,5-dimethyl-7-nitro-2-oxo-2,3-dihydrobenzofuran-3-yl pivalate (**5j**) were isolated in 53 and 14% yield, respectively (eq 3).




(3)

Next, the effect of an alkyl substituent at the C-3 position, on the oxidative dimerization of 3-alkylbenzofurans, was investigated (Scheme 2). The substitution of the methyl group with an ethyl, *n*-butyl, iso-propyl, and benzyl group afforded reasonable yields (**7a**: 58%; **7b**: 52%; **7c**: 51%; **7d**: 36%, respectively). The introduction of an electron-donating/-withdrawing group did not affect the yield of the reaction (**7e**: 55%; **7f**: 56%, respectively).

To obtain an insight on the reaction mechanism, the following reactions were carried out (eq 4). When 2-methylbenzofuran (**8**) was reacted under optimized reaction conditions, 2-methylbenzofuran-3-yl pivalate (**9**) was isolated in 52% yield. Under the reaction conditions adopted in this study, 2-methylbenzofuran was inert and reacted with a palladium-coordinated pivalate to afford **9**.



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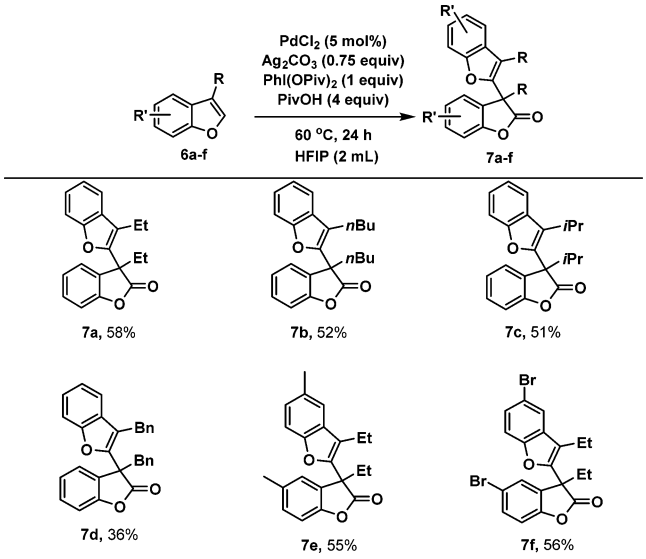
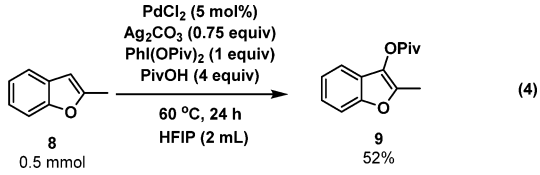
**Scheme 2. Substrate Scope for the Pd-Catalyzed Oxidative Dimerization of 3-Alkylbenzofurans**[a]



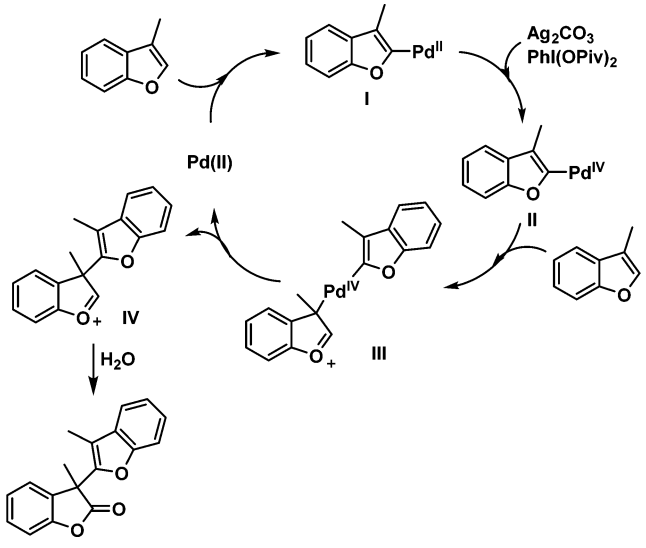

[a]Reaction conditions: **6** (0.5 mmol), $PdCl_2$ (0.025 mmol, 5 mol%), $Ag_2CO_3$ (0.375 mmol, 0.75 equiv), $PhI(OPiv)_2$ (0.5 mmol, 1 equiv), PivOH (2 mmol, 4 equiv), HFIP (2 mL), 60 °C, 24 h. Yields are isolated yield.




(4)

On the basis of these experimental results, together with observations from previous studies,[16] a plausible reaction mechanism can be drawn for the oxidative dimerization of 3-methylbenzofuran in the presence of a palladium compound (Scheme 3). The reaction begins with the formation of palladation product (**I**) via C−H activation. The Pd(II) intermediate is oxidized to a Pd(IV) intermediate (**II**) with the aid of $Ag_2CO_3$ and $PhI(OPiv)_2$.[17] Highly activated intermediate (**II**) reacts with another 3-methylbenzofuran to form palladated Ar−Pd−Ar intermediate (**III**). This then undergoes reductive elimination to form intermediate (**IV**). Subsequent oxidation with a trace amount of water affords the oxidative dimerized product.

**Scheme 3. Proposed Mechanism**




In conclusion, we have developed a unique Pd(II)-catalyzed oxidative dimerization of 3-alkylbenzofuran. The method provides a novel and convenient access to a broad range of [2,3′-bibenzofuran]-2′(3′H)-ones from readily accessible substrates. Both the oxidants and the solvent (HFIP) play critical roles in this reaction. A possible Pd(II)/Pd(IV) mechanism may be involved. Further studies into the scope, mechanism, and synthetic applications of this reaction are in progress.

## EXPERIMENTAL SECTION

All reactions for preparation of novel compounds were conducted under nitrogen using standard Schlenk-type flasks. $^1H$ and $^{13}C$ NMR spectra were recorded at 25 °C on 400 MHz spectrometers: $^1H$ NMR (400 MHz) and $^{13}C$ NMR 100 MHz). $^1H$ NMR spectra were taken in $CDCl_3$ and were referenced to residual TMS (0 ppm) and reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, dd = doublet of doublet, m = multiplet). Chemical shifts of the $^{13}C$ NMR spectra were measured relative to $CDCl_3$ (77.16 ppm). High-resolution mass spectra were obtained using the electronic impact (EI) and fast atom bombardment (FAB) mode using a magnetic sector-electric sector focusing mass analyzer. All samples are prepared as a film on a KBr disk for IR analysis. Reactions were monitored by thin-layer chromatography on 0.25 mm E. Merck silica gel plates (60F-254). The TLC plates were visualized by UV-light (254 nm). Workup procedures were done in air. Flash column chromatography was carried out on silica gel (230−400 mesh). Compound **1a** was commercially obtained. Substrates **1b−l** and **6a−f** were prepared according to literature procedures.[5,18]

**3,5-Dimethylbenzofuran (1b).** Colorless liquid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.30−7.23 (m, 3H), 7.02 (d, $J$ = 8.3 Hz, 1H), 2.39 (s, 3H), 2.14 (s, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 153.8, 141.6, 131.7, 129.2, 125.4, 119.4, 115.4, 110.9, 21.5, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{10}H_{10}O$: 146.0732, found: 146.0731.

**3,5,6-Trimethylbenzofuran (1d).** White solid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.20 (s, 1H), 7.17 (s, 1H), 7.14 (s, 1H), 2.26 (d, $J$ = 2.7 Hz, 6H), 2.11 (s, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 154.3, 140.8, 133.2, 130.8, 127.0, 119.6, 115.3, 111.9, 20.6, 20.1, 8.1. HRMS(EI+) $m/z$: Calcd for $C_{11}H_{12}O$: 160.0888, found: 160.0889.

**5-Bromo-3-methylbenzofuran (1e).** White solid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.55 (s, 1H), 7.30−7.25 (m, 2H), 7.22 (d, $J$ = 8.7 Hz, 1H), 2.11 (s, 3H).$^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 154.1, 142.7, 131.2, 127.1, 122.4, 115.5, 115.4, 112.9, 7.9. HRMS(EI+) $m/z$: Calcd for $C_9H_7BrO$: 209.9680, found: 209.9678.

**5-Fluoro-3-methylbenzofuran (1f).** Colorless liquid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.34 (s, 1H), 7.27 (dd, $J$ = 8.9, 4.1 Hz, 1H), 7.07 (dd, $J$ = 8.5, 2.5 Hz, 1H), 6.90 (td, $J$ = 9.0, 2.6 Hz, 1H), 2.12 (s, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 159.2 (d, $J$ = 237.8 Hz), 149.7 (d, $J$ = 378.5 Hz), 143.3 (d, $J$ = 1.7 Hz), 130.0 (d, $J$ = 10.0 Hz), 116.1 (d, $J$ = 3.9 Hz), 112.0 (d, $J$ = 9.3 Hz), 111.7, 105.1 (d, $J$ = 24.7 Hz), 8.0. HRMS(EI+) $m/z$: Calcd for $C_9H_7FO$: 150.0481, found: 150.0478.

**5-Chloro-3-methylbenzofuran (1g).** Colorless liquid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.39 (s, 1H), 7.31 (s, 1H), 7.26 (dd, $J$ = 8.7, 2.3 Hz, 1H), 7.14 (dd, $J$ = 8.7, 2.0 Hz, 1H), 2.11 (s, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 153.7, 142.9, 130.5, 128.0, 124.4, 119.3, 115.6, 112.4, 7.9. HRMS(EI+) $m/z$: Calcd for $C_9H_7ClO$: 166.0185, found: 166.0184.

**6-Chloro-3-methylbenzofuran (1h).** Colorless liquid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.37 (s, 1H), 7.30 (dd, $J$ = 9.7, 4.7 Hz, 2H), 7.13 (d, $J$ = 8.3 Hz, 1H), 2.13 (s, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 155.4, 142.2, 130.1, 127.8, 123.1, 120.1, 115.7, 112.0, 7.9. HRMS(EI+) $m/z$: Calcd for $C_9H_7ClO$: 166.0185, found: 166.0186.

**5,7-Dichloro-3-methylbenzofuran (1i).** White solid. $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.36 (s, 1H), 7.26 (s, 1H), 7.16 (s, 1H), 2.09 (s,



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3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 149.7, 143.5, 131.5, 128.3, 124.3, 118.0, 117.4, 116.4, 7.9. HRMS(EI+) $m/z$: Calcd for $C_9H_6Cl_2O$: 199.9796, found: 199.9792.

**3,5-Dimethyl-7-nitrobenzofuran (1j).** Yellow solid. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.89 (s, 1H), 7.55 (s, 1H), 7.51 (s, 1H), 2.46 (s, 3H), 2.20 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 145.8, 143.9, 143.8, 133.2, 132.6, 126.6, 121.4, 115.8, 21.1, 7.7. HRMS(EI+) $m/z$: Calcd for $C_{10}H_9NO_3$: 191.0582, found: 191.0581.

**3-Methylnaphtho[1,2-*b*]furan (1k).** Colorless liquid. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 8.25 (d, $J$ = 8.2 Hz, 1H), 7.87 (d, $J$ = 8.2 Hz, 1H), 7.61 (d, $J$ = 8.5 Hz, 1H), 7.55−7.48 (m, 3H), 7.42 (q, $J$ = 7.4 Hz, 1H), 2.26 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 150.9, 140.8, 131.5, 128.4, 126.3, 125.1, 124.5, 123.0, 121.6, 120.2, 118.2, 116.8, 8.2. HRMS(EI+) $m/z$: Calcd for $C_{13}H_{10}O$: 182.0732, found: 182.0730.

**3-Ethyl-5-methylbenzofuran (6e).** Colorless liquid. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.27 (s, 1H), 7.27−7.24 (m, 2H), 7.01 (d, $J$ = 8.0 Hz, 1H), 2.62−2.56 (m, 2H), 2.37 (s, 3H), 1.24 (t, $J$ = 7.5 Hz, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 154.0, 140.8, 131.7, 128.4, 125.4, 122.2, 119.5, 111.0, 21.5, 17.1, 13.7. HRMS(EI+) $m/z$: Calcd for $C_{11}H_{12}O$: 160.0888, found: 160.0889.

**5-Bromo-3-ethylbenzofuran (6f).** Colorless liquid. $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.58 (d, $J$ = 1.7 Hz, 1H), 7.30 (s, 1H), 7.29−7.26 (m, 1H), 7.23 (d, $J$ = 8.7 Hz, 1H), 2.57 (d, $J$ = 7.5 Hz, 2H), 1.24 (d, $J$ = 7.5 Hz, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 154.3, 142.0, 130.4, 127.1, 122.5, 122.1, 115.4, 113.0, 17.0, 13.5. HRMS(EI+) $m/z$: Calcd for $C_{10}H_9BrO$: 223.9837, found: 223.9834.

**General Procedure for Palladium-Catalyzed Oxidative Dimerization of 3-Alkylbenzofurans.** Reactions were performed in a Schlenk tube equipped with a stirring bar and capped with a rubber septum. The followings were placed in the tube flask in order: 0.025 mmol of catalyst, 0.375 mmol of silver carbonate, 0.5 mmol of $PhI(OPiv)_2$, 2 mmol of pivalic acid, 0.5 mmol of 3-methylbenzofuran, and 2 mL of HFIP. The mixture was stirred at 60 °C for 24 h. The mixture was filtered to remove catalyst residue, and the filtrate was evaporated under reduced pressures. The residue was purified by flash chromatography on silica gel (*n*-hexane/ethyl acetate = 10/1), and the product **4a** was obtained with 73% yield.

*3,3′-Dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4a**).* Pale yellow oil. (73%, 50.8 mg). $R_f$ = 0.59 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.35 (t, $J$ = 8.0 Hz, 2H), 7.27 (t, $J$ = 7.8 Hz, 1H), 7.22−7.17 (m, 2H), 7.13 (d, $J$ = 7.7 Hz, 2H), 7.09 (d, $J$ = 7.5 Hz, 1H), 1.97 (s, 3H), 1.81 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 176.5, 153.6, 152.6, 147.9, 131.4, 130.5, 129.5, 124.9, 124.6, 124.3, 122.6, 119.4, 112.3, 111.2 (C2), 48.2, 23.1, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{18}H_{14}O_3$: 278.0943, found: 278.0939. IR (neat): 1811.15 cm$^{-1}$ ($\nu_{C=O}$).

*3,3′,5,5′-Tetramethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4b**).* Pale yellow oil. (63%, 48.3 mg). $R_f$ = 0.52 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.23 (d, $J$ = 8.4 Hz, 1H), 7.11 (s, 1H), 7.02 (m, 3H), 6.95 (s, 1H), 2.34 (s, 3H), 2.22 (s, 3H), 1.93 (s, 3H), 1.78 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 176.9, 152.0, 150.4, 148.3, 134.6, 132.1, 131.4, 130.6, 129.8, 125.7, 124.6, 119.2, 111.82, 110.70, 110.67, 48.3, 23.0, 21.5, 21.2, 7.9 HRMS(EI+) $m/z$: Calcd for $C_{20}H_{18}O_3$: 306.1256, found: 306.1257. IR (neat): 1805.07 cm$^{-1}$ ($\nu_{C=O}$).

*3,3′,6,6′-Tetramethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4c**).* Pale yellow oil. (73%, 48.3 mg). $R_f$ = 0.56 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.20 (d, $J$ = 7.9 Hz, 1H), 7.16 (s, 1H), 7.03 (s, 1H), 6.94 (d, $J$ = 8.6 Hz, 1H), 6.93 (s, 1H), 6.88 (d, $J$ = 7.7 Hz, 1H), 2.37 (s, 3H), 2.32 (s, 3H), 1.92 (s, 3H), 1.78 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 177.0, 154.0, 152.6, 147.5, 140.0, 134.8, 128.5, 128.1, 125.5, 123.9, 123.8, 118.8, 112.0, 111.7, 111.4, 48.0, 23.1, 21.9, 21.8, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{20}H_{18}O_3$: 306.1256, found: 306.1253. IR (neat): 1805.24 cm$^{-1}$ ($\nu_{C=O}$).

*3,3′,5,5′,6,6′-Hexamethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4d**).* Pale yellow oil. (73%, 47.7 mg). $R_f$ = 0.51 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.14 (s, 1H), 7.07 (s, 1H), 6.90, 6.89 (s, 2H), 2.26 (s, 3H), 2.23 (s, 3H), 2.21 (s, 3H), 2.11 (s, 3H), 1.90 (s, 3H), 1.78 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 177.3, 152.5, 150.7, 147.5, 138.1, 133.5, 133.1, 131.1, 128.8, 128.4, 124.8, 119.4, 112.0, 111.6, 111.6, 48.2, 23.1, 20.6, 20.4, 20.1, 19.6, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{22}H_{22}O_3$: 334.1569, found: 334.1571. IR (neat): 1805.58 cm$^{-1}$ ($\nu_{C=O}$).

*5,5′-Dibromo-3,3′-dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4e**).* Pale yellow oil. (71%, 77.4 mg). $R_f$ = 0.50 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.48 (d, $J$ = 1.8 Hz, 1H), 7.42−7.39 (m, 1H), 7.31−7.28 (m, 2H), 7.23 (d, $J$ = 8.7 Hz, 1H), 7.03 (d, $J$ = 8.5 Hz, 1H), 1.95 (s, 3H), 1.84 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 175.4, 152.4, 151.4, 148.5, 133.1, 132.7, 132.3, 127.8, 127.3, 122.3, 117.6, 116.0, 113.0, 112.8, 112.3, 48.3, 23.0, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{18}H_{12}Br_2O_3$: 433.9153, found: 433.9150. IR (neat): 1808.86 cm$^{-1}$ ($\nu_{C=O}$).

*5,5′-Difluoro-3,3′-dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4f**).* Colorless oil. (67%, 52.6 mg). $R_f$ = 0.60 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.29 (dd, $J$ = 8.9, 4.0 Hz, 1H), 7.11−7.08 (m, 1H), 7.02−6.97 (m, 2H), 6.95−6.89 (m, 2H), 1.96 (s, 3H), 1.83 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 176.1, 160.9 (d, $J$ = 64.9 Hz), 158.5 (d, $J$ = 59.6 Hz), 149.8, 149.1, 148.3 (d, $J$ = 2.2 Hz), 132.5 (d, $J$ = 8.7 Hz), 131.2 (d, $J$ = 10.2 Hz), 116.4 (d, $J$ = 24.5 Hz), 112.9 (d, $J$ = 4.1 Hz), 112.6 (d, $J$ = 26.5 Hz), 112.3 (d, $J$ = 8.2 Hz), 112.0 (d, $J$ = 9.6 Hz), 111.7 (d, $J$ = 25.4 Hz), 105.1 (d, $J$ = 24.9 Hz), 48.8, 23.0, 8.1. HRMS(EI+) $m/z$: Calcd for $C_{18}H_{12}F_2O_3$: 314.0755, found: 314.0757. IR (neat): 1810.33 cm$^{-1}$ ($\nu_{C=O}$).

*5,5′-Dichloro-3,3′-dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4g**).* Pale yellow oil. (77%, 66.8 mg). $R_f$ = 0.55 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.32 (d, $J$ = 1.9 Hz, 1H), 7.29−7.25 (m, 2H), 7.18−7.15 (m, 2H), 7.08 (d, $J$ = 8.6 Hz, 1H), 1.95 (s, 3H), 1.84 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 175.5, 152.0, 150.9, 148.7, 132.7, 131.7, 130.4, 129.8, 128.6, 125.1, 124.5, 119.2, 112.5, 112.4, 112.3, 48.5, 23.0, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{18}H_{12}Cl_2O_3$: 346.0163, found: 346.0166. IR (neat): 1816.62 cm$^{-1}$ ($\nu_{C=O}$).

*6,6′-Dichloro-3,3′-dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**4h**).* Pale yellow oil. (81%, 70.3 mg). $R_f$ = 0.53 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.37 (s, 1H), 7.26 (d, $J$ = 8.3 Hz, 1H), 7.16 (m, 2H), 7.11 (d, $J$ = 8.2 Hz, 2H), 1.94 (s, 3H), 1.84 (s, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 175.6, 153.6, 152.9, 148.1, 135.2, 130.7, 129.6, 129.0, 125.3, 125.0, 123.6, 120.1, 112.5, 112.2, 111.8, 47.9, 23.0, 8.0. HRMS(EI+) $m/z$: Calcd for $C_{18}H_{12}Cl_2O_3$: 346.0163, found: 346.0162. IR (neat): 1821.74 cm$^{-1}$ ($\nu_{C=O}$).

*5,7-Dichloro-3-methylbenzofuran-2-yl Pivalate (**5i**).* Colorless oil. (53%, 31.8 mg). $R_f$ = 0.48 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.24 (d, $J$ = 1.0 Hz, 1H), 7.17 (d, $J$ = 1.0 Hz, 1H), 1.94 (s, 3H), 1.34 (s, 9H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 174.9, 144.4, 132.2, 128.8, 123.9, 117.7, 117.0, 99.5, 39.5, 27.1, 6.8. HRMS(EI+) $m/z$: Calcd for $C_{14}H_{14}Cl_2O_3$: 300.0320, found: 300.0321. IR (neat): 1787.60 cm$^{-1}$ ($\nu_{C=O}$).

*3,5-Dimethyl-7-nitrobenzofuran-2-yl Pivalate (**5j**).* Yellow solid. (14% yield, 20.4 mg). $R_f$ = 0.36 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.81 (s, 1H), 7.45 (s, 1H), 2.43 (s, 3H), 1.99 (s, 3H), 1.36 (s, 9H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 174.9, 152.0, 140.5, 133.6, 133.0, 126.0, 120.7, 98.8, 39.5, 27.1, 21.3, 6.7. HRMS(FAB) $m/z$: Calcd for $C_{15}H_{17}NO_5$ $[M+H]^+$: 292.1185, found: 292.1181. IR (neat): 1777.65 cm$^{-1}$ ($\nu_{C=O}$). m.p.: 144 °C.

*3,3′-Diethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7a**).* Colorless oil. (58%, 44.4 mg). $R_f$ = 0.60 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.38 (dd, $J$ = 8.0, 2.9 Hz, 2H), 7.28 (t, $J$ = 7.8 Hz, 1H), 7.20 (m, 2H), 7.11 (m, 3H), 2.62−2.55 (m, 1H), 2.49 (dd, $J$ = 14.2, 6.9 Hz, 1H), 2.26 (q, $J$ = 7.5 Hz, 2H), 0.90 (t, $J$ = 7.5 Hz, 3H), 0.78 (t, $J$ = 7.4 Hz, 3H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 176.1, 153.8, 153.2, 147.6, 129.6, 129.51 (C2), 124.8, 124.54, 124.46, 122.6, 119.7, 118.7, 111.3, 111.0, 53.4, 29.5, 16.8, 13.9, 8.6. HRMS(EI+) $m/z$: Calcd for $C_{20}H_{18}O_3$: 306.1256, found: 306.1254. IR (neat): 1803.60 cm$^{-1}$ ($\nu_{C=O}$).

*3,3′-Dibutyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7b**).* Colorless oil. (52%, 47.1 mg). $R_f$ = 0.65 (Hex/EA = 5/1). $^1$H NMR (400 MHz, $CDCl_3$): $\delta$ 7.38 (t, $J$ = 7.4 Hz, 4H), 7.30−7.26 (m, 2H), 7.23−7.16 (m, 5H), 7.11 (m, 6H), 2.57−2.50 (m, 2H), 2.48−2.41 (m, 2H), 2.17 (t, $J$ = 7.8 Hz, 4H), 1.33−1.24 (m, 6H), 1.17−1.00 (m, 10H), 0.79 (t, $J$ = 7.3 Hz, 6H), 0.70 (t, $J$ = 7.2 Hz, 6H). $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$ 176.2, 153.8, 153.1, 147.8, 130.0, 129.9, 129.5, 124.8, 124.6, 124.4, 122.5, 119.8, 117.6, 111.3, 111.0, 52.8, 35.9, 31.7, 26.2, 23.3, 22.9, 22.8,



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13.9, 13.9. HRMS(EI+) *m/z*: Calcd for $C_{24}H_{26}O_3$: 362.1882, found: 362.1879. IR (neat): 1810.88 $cm^{-1}$ ($\nu_{C=O}$).

*3,3′-Diisopropyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7c**).* Colorless oil. (51%, 42.6 mg). $R_f$ = 0.62 (Hex/EA = 5/1). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.57 (d, *J* = 7.8 Hz, 1H), 7.39 (d, *J* = 8.2 Hz, 1H), 7.31−7.24 (m, 2H), 7.18 (d, *J* = 0.6 Hz, 1H), 7.13−7.07 (m, 3H), 3.14 (m, 1H), 2.63 (m, 1H), 1.20 (d, *J* = 7.0 Hz, 3H), 1.02 (d, *J* = 6.9 Hz, 3H), 0.97 (d, *J* = 6.8 Hz, 3H), 0.88 (d, *J* = 6.7 Hz, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 175.6, 154.3, 153.2, 146.3, 129.5, 128.5, 128.1, 125.4, 124.4, 124.1, 123.5, 122.2, 121.8, 111.6, 110.8, 57.0, 35.0, 25.1, 21.6, 21.5, 17.9, 17.4. HRMS(EI+) *m/z*: Calcd for $C_{22}H_{22}O_3$: 334.1569, found: 334.1570. IR (neat): 1806.30 $cm^{-1}$ ($\nu_{C=O}$).

*3,3′-Dibenzyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7d**).* Pale yellow oil. (36%, 38.7 mg). $R_f$ = 0.52 (Hex/EA = 5/1). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.48 (d, *J* = 8.3 Hz, 1H), 7.23 (m, 1H), 7.16 (d, *J* = 7.8 Hz, 1H), 7.12−7.08 (m, 2H), 7.08−6.94 (m, 8H), 6.83−6.76 (m, 4H), 6.72 (d, *J* = 8.0 Hz, 1H), 3.83 (s, 2H), 3.61 (t, *J* = 10.6 Hz, 2H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 175.1, 154.0, 152.9, 148.3, 138.7, 133.8, 130.4, 130.0, 129.7, 128.4, 128.3, 128.2, 127.4, 126.3, 125.2, 124.8, 124.4, 122.9, 120.4, 116.0, 111.4, 111.0, 54.7, 42.2, 29.3. HRMS(EI+) *m/z*: Calcd for $C_{30}H_{22}O_3$: 430.1569, found: 430.1568. IR (neat): 1809.37 $cm^{-1}$ ($\nu_{C=O}$).

*3,3′-Diethyl-5,5′-dimethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7e**).* Pale yellow oil. (55%, 46.0 mg). $R_f$ = 0.69 (Hex/EA = 5/1). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.25 (d, *J* = 8.4 Hz, 1H), 7.15 (s, 1H), 7.05 (d, *J* = 7.6 Hz, 1H), 6.99 (m, 2H), 6.95 (s, 1H), 2.58−2.52 (m, 1H), 2.48−2.42 (m, 1H), 2.34 (s, 3H), 2.23 (s, 3H), 0.88 (t, *J* = 7.5 Hz, 3H), 0.76 (t, *J* = 7.4 Hz, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 176.5, 152.3, 151.0, 147.9, 134.5, 132.0, 129.8, 129.7, 129.6, 125.6, 124.8, 119.4, 118.3, 110.8, 110.5, 53.5, 29.4, 21.5, 21.2, 16.8, 13.8, 8.6. HRMS(EI+) *m/z*: Calcd for $C_{22}H_{22}O_3$: 334.1569, found: 334.1571. IR (neat): 1804.08 $cm^{-1}$ ($\nu_{C=O}$).

*5,5′-Dibromo-3,3′-diethyl-[2,3′-bibenzofuran]-2′(3′H)-one (**7f**).* Colorless oil. (56%, 65.0 mg). $R_f$ = 0.66 (Hex/EA = 5/1). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.52 (d, *J* = 1.7 Hz, 1H), 7.42 (dd, *J* = 8.5, 2.1 Hz, 1H), 7.31 (dd, *J* = 9.1, 1.8 Hz, 2H), 7.25 (d, *J* = 8.7 Hz, 1H), 7.02 (d, *J* = 8.5 Hz, 1H), 2.55 (dd, *J* = 13.8, 7.3 Hz, 1H), 2.45 (q, *J* = 14.0, 7.2 Hz, 1H), 2.26 (q, *J* = 7.5 Hz, 2H), 0.93 (t, *J* = 7.5 Hz, 3H), 0.78 (t, *J* = 7.4 Hz, 3H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 174.9, 152.6, 152.0, 148.2, 132.7, 131.5, 131.4, 127.7, 127.5, 122.5, 118.8, 117.5, 115.9, 112.9, 112.8, 53.6, 29.6, 16.8, 13.8, 8.5. HRMS(EI+) *m/z*: Calcd for $C_{20}H_{16}Br_2O_3$: 461.9466, found: 461.9465. IR (neat): 1808.48 $cm^{-1}$ ($\nu_{C=O}$).

*2-Methylbenzofuran-3-yl Pivalate (**9**).* Colorless liquid. (52%, 60.4 mg). $R_f$ = 0.52 (Hex/EA = 5/1). $^1H$ NMR (400 MHz, $CDCl_3$): $\delta$ 7.29 (d, *J* = 7.3 Hz, 1H), 7.19−7.16 (m, 1H), 7.12 (td, *J* = 7.1, 1.3 Hz, 2H), 2.26 (s, 3H), 1.34 (s, 9H). $^{13}C$ NMR (100 MHz, $CDCl_3$): $\delta$ 176.2, 152.3, 144.1, 130.1, 123.9, 123.6, 122.7, 117.8, 111.4, 39.4, 27.4, 11.3. HRMS(EI+) *m/z*: Calcd for $C_{14}H_{16}O_3$: 232.1099, found: 232.1098. IR (neat): 1751.66 $cm^{-1}$ ($\nu_{C=O}$).

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b02864.

Experimental procedures and spectral data for the products (PDF)

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### Notes

The authors declare no competing financial interest.

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