Divergent Synthesis of Isonitriles and Nitriles by Palladium-Catalyzed Benzylic Substitution with TMSCN

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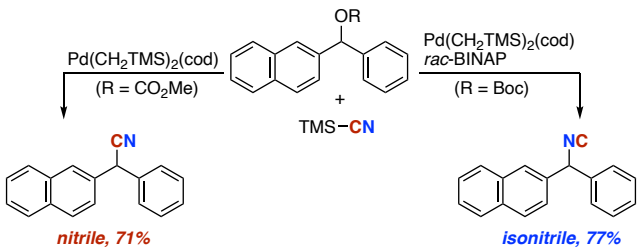
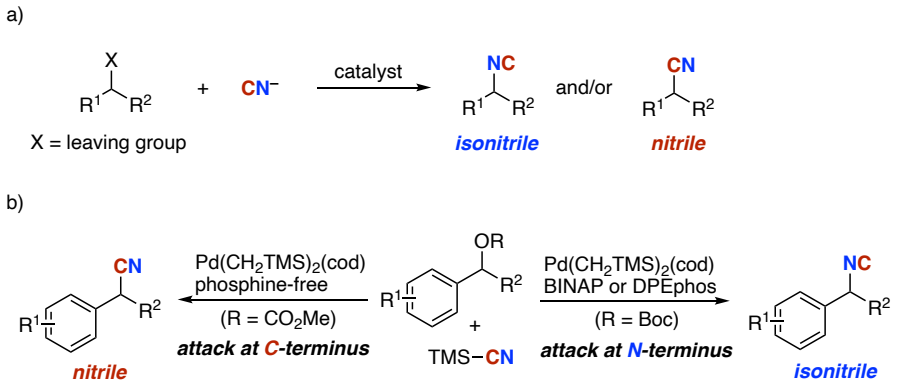


Ligand-controlled palladium-catalyzed divergent synthesis of isonitriles and nitriles from benzylic carbonates and TMSCN has been developed. The BINAP- or DPEphos-ligated palladium catalyst selectively provides the corresponding benzylic isonitriles, whereas their regioisomers, benzylic nitriles, are formed exclusively under phosphine-ligand-free conditions. Mechanistic studies reveal that the isonitrile is the primary product under both conditions, but it is isomerized into the nitrile in the absence of ancillary phosphine ligands.

Introduction

Isonitriles and nitriles are regioisomers to each other, and both are important nitrogen-containing compounds in organic chemistry. The former is not only the well-known reactant in Passerini and Ugi multi-component coupling reactions[1] but also frequently occurring in natural products.[2] The latter is also found in biologically active compounds[3] and the valuable synthetic intermediate for amines and carbonyl compounds.[4] Therefore, their selective synthesis has been one of the long-standing research subjects in synthetic communities. Among numerous reports,[5] the metal-mediated substitution reaction of carbon electrophiles with "CN" nucleophiles is the most classical but the most reliable strategy. However, the "CN" nucleophiles have the ambident character; they can work as both the *N*-terminus nucleophile and *C*-terminus nucleophile to form the corresponding isonitrile and nitrile, respectively (Scheme 1a). Accordingly, the control of reaction regioselectivity (*N*-attack vs *C*-attack) is a great synthetic challenge. Extensive screening of catalysts/ligands, "CN" reagents, additives, and reaction conditions often provided one regioisomer selectively, but another regioisomer was generally difficult to access by simple ligand modifications.[6-8] Herein, we report ligand-controlled palladium-catalyzed divergent synthesis of regioisomeric benzylic isonitriles and nitriles: a bisphosphine-ligated palladium catalyst couples the benzyl carbonates with TMSCN to form the corresponding benzylic isonitriles with high *N*-terminus selectivity (Scheme 1b). On the other hand, the benzylic nitriles are obtained exclusively under ancillary phosphine ligand-free conditions. The newly developed protocols can provide a divergent approach to isonitriles and nitriles from the readily available benzyl carbonates.

Scheme 1. Substitution Approaches to Isonitriles and Nitriles from Carbon Electrophiles and the Ambident "CN" Nucleophile; (a) Meta-mediated Substitution of Carbon Electrophiles with the Ambident "CN" Nucleophile; (b) Ligand-controlled Divergent Synthesis of Benzylic Isonitriles and Nitriles with TMSCN (This Work)

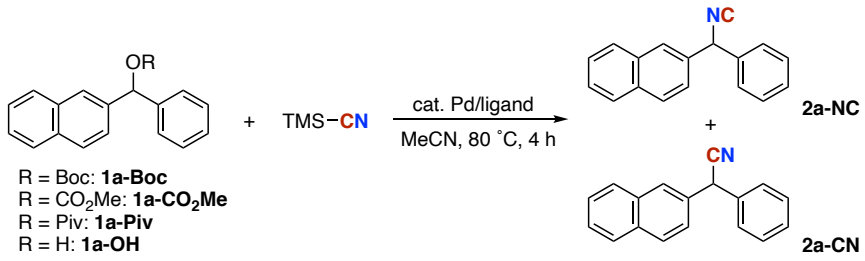


Results and Discussion

Recently, our research group has focused on the unique reactivity of benzylic C–O electrophiles and succeeded in the development of palladium-catalyzed benzylic substitution reactions with various nucleophiles including azoles, terminal alkynes, active methylenes, amides/amines, phenols, sulfinates, phosphonates, and olefins.[9] During the continuing interest in this chemistry, we tested some "CN" nucleophiles in the reaction of *tert*-butyl diarylmethyl carbonate **1a-Boc** with CpPd(η^3-C_3H_5) catalyst, *rac*-BINAP ligand, and MeCN solvent at 80 ˚C. After initial brief screening, TMS-CN was found to uniquely promote the reaction (Table 1). Additionally, the corresponding benzylic isonitrile **2a-NC** was mainly formed (67% ^{1}H NMR yield) along with a small amount of nitrile **2a-CN** (6% ^{1}H NMR yield; entry 1). This preliminary but intriguing isonitrile selectivity prompted us to further investigate the reaction conditions. Several bidentate phosphine ligands bearing relatively large bite angles worked, but only with DPEphos proving efficiency and isonitrile/nitrile selectivity comparable to *rac*-BINAP (entries 2–4). On the other hand, the bisphosphine ligands with smaller bite angles such as dppbz completely shut down the reaction (entry 5). Additional investigations of Pd catalyst precursors revealed that Pd($CH_2TMS)_2$(cod) showed somewhat better performance even at lower temperature (60 ˚C), and finally,

the corresponding isonitrile **2a-NC** was isolated in 77% yield (entries 6 and 7). In sharp contrast, without any external phosphine ligands the regioselectivity was switched, giving the regioisomeric benzyl nitrile **2a-CN** predominantly (entry 8). For the nitrile synthesis, the methyl carbonate **1a-CO_2Me** was a better starting substrate from the viewpoints of reactivity and nitrile/isonitrile selectivity, and the desired **2a-CN** was obtained in 71% isolated yield with high regioselectivity (entry 9), while the reaction of **1a-Piv** and **1a-OH** was sluggish even at higher temperature (entries 10 and 11). We confirmed no conversion of **1a-Boc** in the absence of any Pd sources (entry 12), thus indicating that Pd catalysts are necessary for both isonitrile and nitrile formations. Some additional observations are to be noted: other potential "CN" nucleophiles such as acetone cyanohydrin, benzoyl cyanide, and tetrabutylammonium cyanide resulted in no conversion. The reaction was unique to the MeCN solvent, and neither less polar nor much polar solvents gave satisfactory results (see the Supporting Information for more detailed optimization studies).

Table 1. Optimization Studies for Palladium-Catalyzed Benzylic Substitution of Diarylmethanol Derivatives 1a with TMSCN[a]



entry	**1a**	Pd/ligand	yield (%)[b] **2a-NC**	**2a-CN**
1	**1a-Boc**	CpPd(η^3-C_3H_5)/*rac*-BINAP	67	6
2	**1a-Boc**	CpPd(η^3-C_3H_5)/dppf	14	1
3	**1a-Boc**	CpPd(η^3-C_3H_5)/DPEphos	67	7
4	**1a-Boc**	CpPd(η^3-C_3H_5)/xantphos	32	2
5	**1a-Boc**	CpPd(η^3-C_3H_5)/dppbz	trace	0

6	**1a-Boc**	Pd $(CH_2TMS)_2$(cod)/*rac*-BINAP	61	6
7[c]	**1a-Boc**	Pd $(CH_2TMS)_2$(cod)/*rac*-BINAP	(77)	7
8	**1a-Boc**	Pd $(CH_2TMS)_2$(cod)/none	5	71
9[d]	**1a-CO_2Me**	Pd $(CH_2TMS)_2$(cod)/none	0	(71)
10[e]	**1a-Piv**	Pd $(CH_2TMS)_2$(cod)/none	0	31
11[e]	**1a-OH**	Pd $(CH_2TMS)_2$(cod)/none	3	12
12	**1a-Boc**	none/none	0	0

[a] Conditions: **1a** (0.20 mmol), TMSCN (0.30 mmol), Pd (0.010 mmol), ligand (0.010 mmol), MeCN (1.5 mL), 80 ˚C, 4 h, N_2. [b] Estimated by ^{1}H NMR with CH_2Br_2 or 1-methylnaphthalene as the internal standard . Isolated yields in parentheses. [c] With TMSCN (0.80 mmol) and *rac*-BINAP (0.011 mmol) at 60 ˚C for 19 h. [d] For 18 h. [e] At 100 ˚C for 2 h.

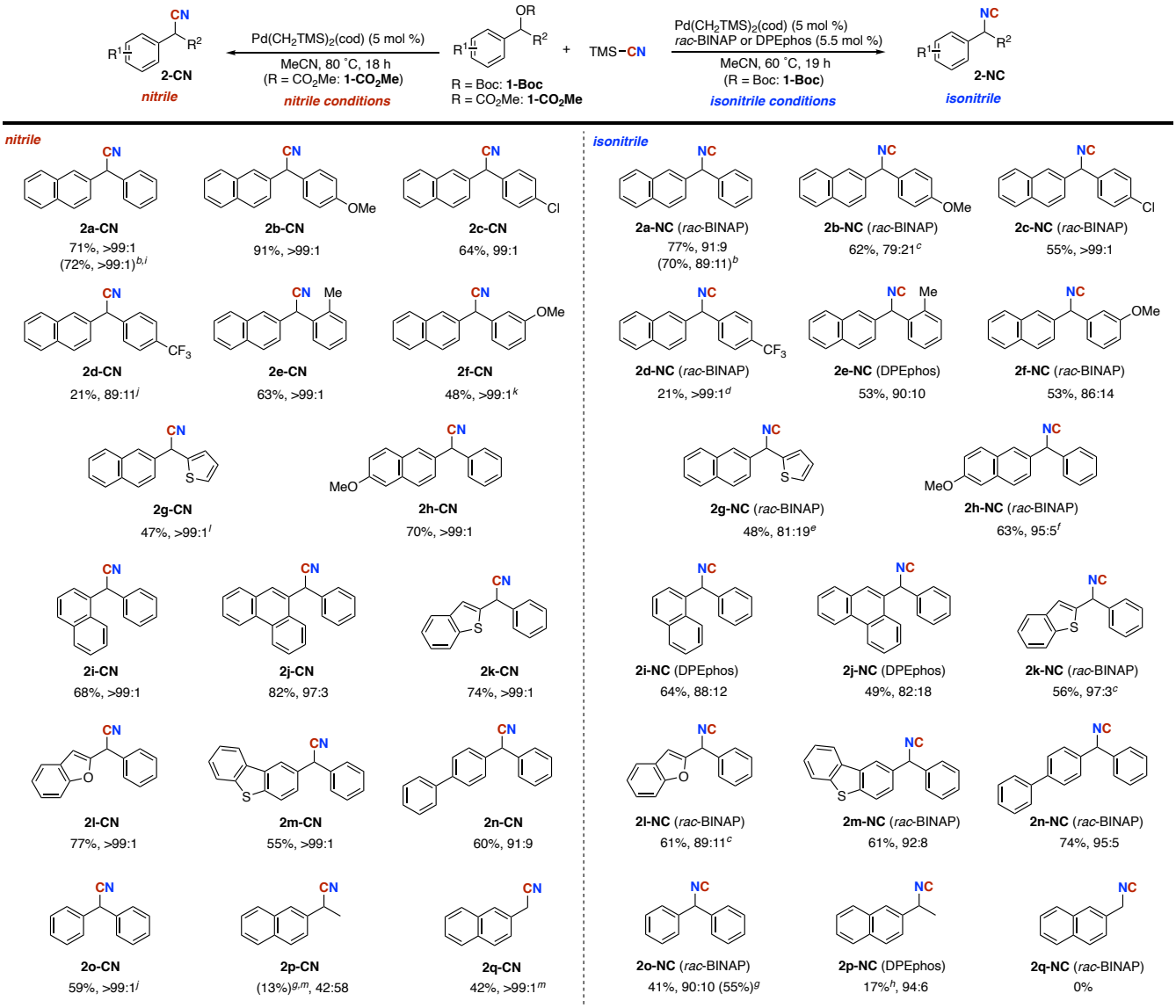
To check the generality of ligand-controlled regioselectivity switching observed in Table 1, we next examined the reaction of various benzylic carbonates **1** with TMSCN under both isonitrile and nitrile conditions (entries 7 and 9 in Table 1, respectively). The representative results are shown in Scheme 2. For the isonitrile selective synthesis (right side in Scheme 2), some minor modifications of reaction temperature and time were often necessary, but the corresponding benzylic isonitriles **2-NC** were obtained with good regioselectivity (isonitrile/nitrile = 79:21 to >99:1). Namely, in addition to the model substrate **1a-Boc**, the methoxy- and chloro-substituted benzylic carbonates were also selectively converted to **2b-NC** and **2c-NC**, respectively. Exceptionally, the introduction of the highly electron-withdrawing trifluoromethyl group interfered with the conversion (**2d-NC**), however, which can provide useful information about the reaction mechanism (vide infra). The ortho- and meta-substituted carbonates could also be employed (**2e-NC** and **2f-NC**). The replacement of the phenyl ring with the thiophene was also possible (**2g-NC**). The 2-naphthalene ring in the model substrate **1a-Boc** could also be replaced with the methoxy-substituted 2-naphthalene, 1-naphthalene, and higher fused phenanthrene

systems (**2h-NC**–**2j-NC**). Moreover, the heteroaromatic benzothiophene-, benzofuran-, and dibenzothiophene-substituted carbonates were viable to afford the corresponding isonitriles **2k-NC**–**2m-NC** in good yield with high isonitrile selectivity. It should be noted that the palladium catalyst was compatible with the monocyclic substituents such as the biphenyl (**2n-NC**) and even simple phenyl groups (**2o-NC**), which are generally challenging substrates in the related cross-coupling reactions with C–O electrophiles.[10] The alkyl-substituted secondary benzyl carbonate (**2p-NC**) and the primary substrate (**2q-NC**) were reluctant to the palladium catalysis. Particularly in the former case, the competitive elimination reaction occurred, and the corresponding vinylnaphthalene was observed. As the ancillary ligand, *rac*-BINAP generally provided the best performance, but in specific cases with the highly sterically congested substrates, DPEphos resulted in better efficiency (**2e-NC**, **2i-NC**, and **2j-NC**). Additionally, the reaction was easily conducted on a 1.0 mmol scale (**2a-NC**) with the maintenance of yield and isonitrile selectivity, thus suggesting the reliability and reproducibility of this protocol.

In almost all cases of nitrile synthesis (left side in Scheme 2), the much better regioselectivity was observed (nitrile/isonitrile = 89:11 to >99:1). As seen in the isonitrile synthesis, the trifluoromethyl-substituted substrate suffered from the low conversion (**2d-CN**), but the reaction was tolerated to the *para*-methoxy, *para*-chloro, *ortho*-methyl, and *meta*-methoxy substituents to furnish the corresponding nitriles **2b-CN**, **2c-CN**, **2e-CN**, and **2f-CN** in good to high yields. In the synthesis of thiophene-substituted **2g-CN**, the corresponding starting methyl carbonate **1g-CO$_2$Me** was too unstable to be prepared in a pure form, but the use of more stable *tert*-butyl carbonate **1g-Boc** afforded an acceptable yield. The palladium catalysis also accommodated 2-methoxynaphthalene (**2h-CN**), more fused aromatics (**2i-CN** and **2j-CN**), and heteroaromatic substrates (**2k-CN**–**2m-CN**). Additionally notable is the successful conversion of the monocyclic systems (**2n-CN** and **2o-CN**) and primary benzyl carbonate (**2q-CN**). Only one exception is the alkyl-substituted secondary benzyl carbonate: the targeted nitrile **2p-CN** and regioisomeric isonitrile **2p-NC** were formed only in 15 and 19% yield, respectively. Additionally, as the same under the isonitrile conditions, the elimination byproduct was observed in the crude mixture.

Also in the nitrile synthesis, the scale-up reaction was feasible without any erosion of yield and nitrile/isonitrile selectivity (**2a-CN**).

Scheme 2. Synthesis of Isonitriles 2-NC and Nitriles 2-CN by Ligand-Controlled Palladium-Catalyzed Regiodivergent Benzylic Substitution of Benzyl Carbonates 1 with TMSCN[a]

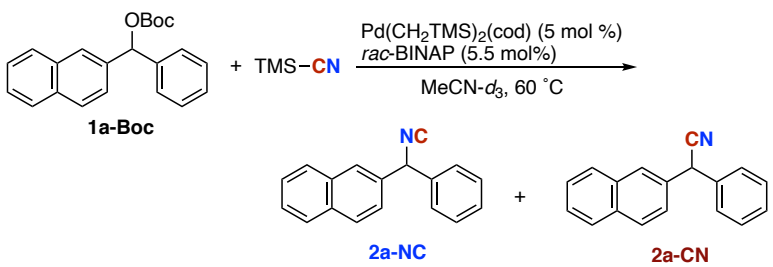


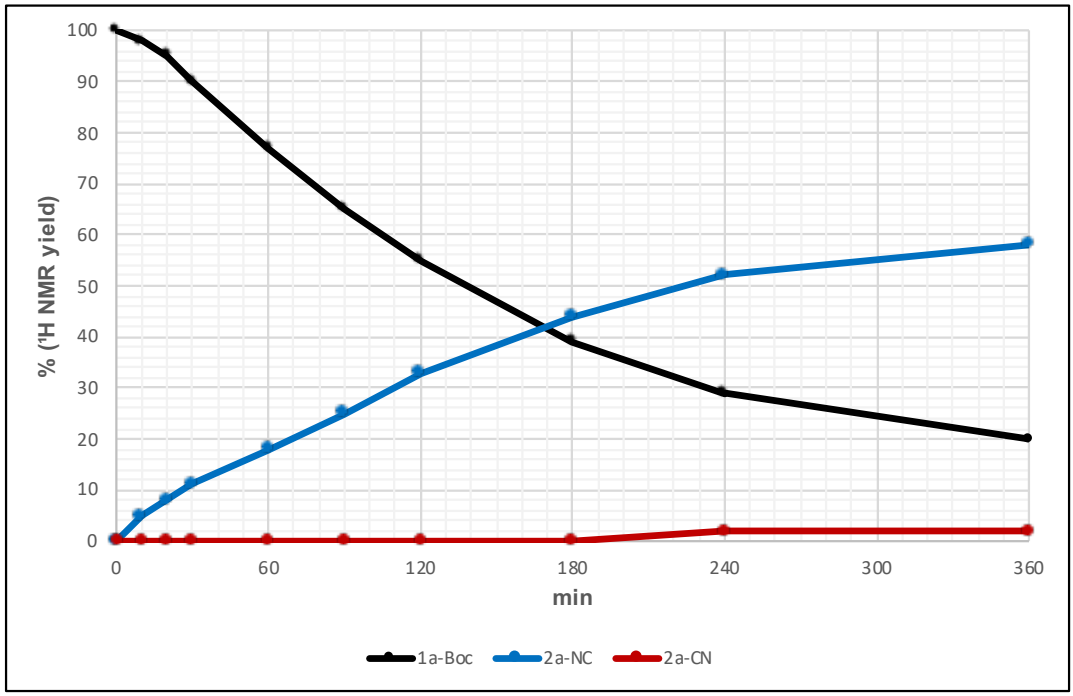
[a] Isonitrile conditions: **1-Boc** (0.20 mmol), TMSCN (0.80 mmol), $Pd(CH_2TMS)_2(cod)$ (0.010 mmol), *rac*-BINAP or DPEphos (0.011 mmol), MeCN (1.5 mL), 60 ˚C, 19 h, N_2; nitrile conditions: **1-CO_2Me** (0.20 mmol), TMSCN (0.30 mmol), $Pd(CH_2TMS)_2(cod)$ (0.010 mmol), MeCN (1.5 mL), 80 ˚C, 18 h, N_2. Isolated yields of pure isonitrile or nitrile are shown. The ratios of isonitrile/nitrile (right side) or nitrile/isonitrile (left side) in the crude mixture are also shown. [b] On a 1.0 mmol scale. [c] At 40 ˚C. [d] For 36 h. [e] At 40 ˚C for 28 h. [f] At 40 ˚C for 24 h. [g] ^1H NMR yield. The lower isolated is due to the partial decomposition of **2o-NC** during column purification. [h] At 70 ˚C. [i] With 2 mol % of $Pd(CH_2TMS)_2(cod)$. [j]

At 100 ˚C. [k] With 0.80 mmol of TMSCN. [l] At 60 ˚C for 1 h using **1g-Boc**. [m] With 10 mol % of $Pd(CH_2TMS)_2(cod)$ and TMSCN (0.80 mmol) at 120 ˚C for 18 h.

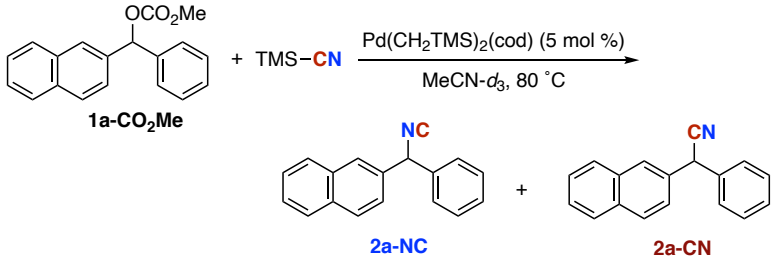
To get insight into the reaction mechanism, particularly, about the isonitrile/nitrile selectivity, we monitored the reaction progress using ^1H NMR. Under the isonitrile conditions, alongside the consumption of starting **1a-Boc**, the corresponding isonitrile **2a-NC** gradually formed. On the other hand, the regioisomeric nitrile **2a-CN** was detected after 180 min, but its amount was kept in less than 5% in 6 h reaction periods (Figure 1a). In contrast, under the nitrile conditions ca. 20% of **1a-CO_2Me** was rapidly converted to the isonitrile **2a-NC** just within the initial 2 min periods, and its amount reached ca. 40% in 10 min. After that, the isonitrile **2a-NC** gradually decreased, and instead, the nitrile **2a-CN** increased to become the major product in 35 min (Figure 1b). These phenomena suggest that the isonitrile **2a-NC** is the kinetically favored primary product under both nitrile and isonitrile conditions, but it can be isomerized into the regioisomeric nitrile **2a-CN** only under the phosphine-free nitrile conditions. Actually, the isolated isonitrile **2a-NC** was converted to the nitrile **2a-CN** under the nitrile conditions with $Pd(CH_2TMS)_2(cod)$ and TMSCN (Scheme 3a),[11] whereas the much slower isomerization was observed under the isonitrile conditions using $Pd(CH_2TMS)_2(cod)$/*rac*-BINAP and TMSCN (Scheme 3b). A similar isonitrile-to-nitrile isomerization was reported in the presence of strong Lewis acids such as $AgClO_4$[6d] and $TiCl_4$.[7a] On the other hand, no conversion of the nitrile **2a-CN** occurred under the isonitrile conditions (Scheme 3c).

a) isonitrile conditions





b) nitrile conditions



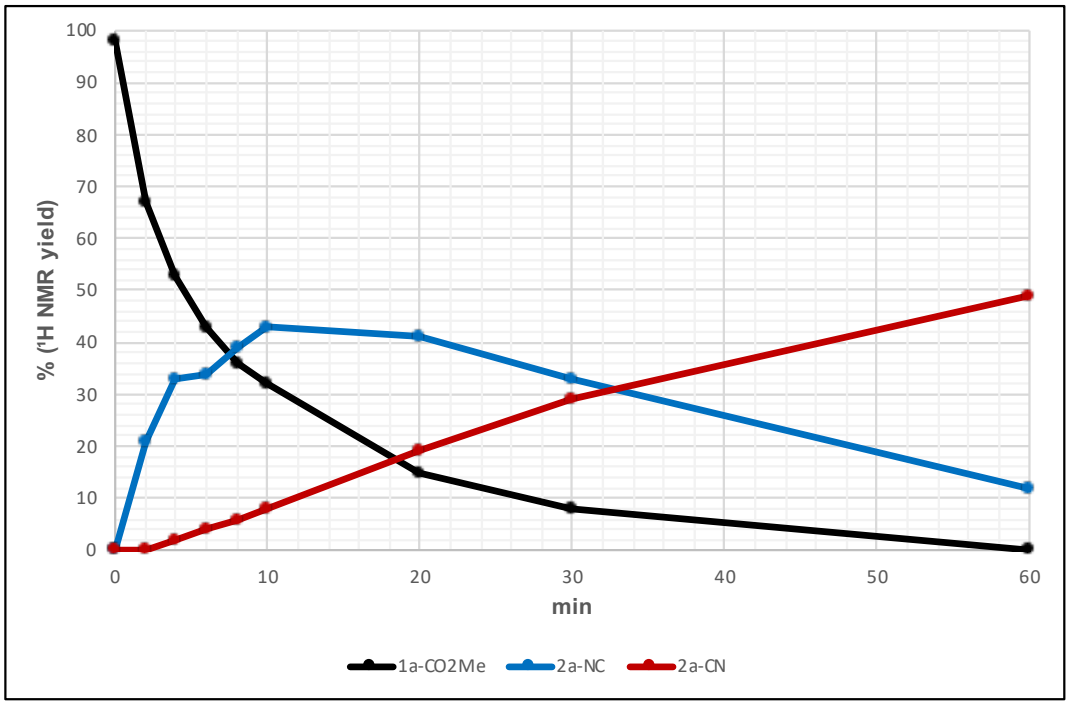
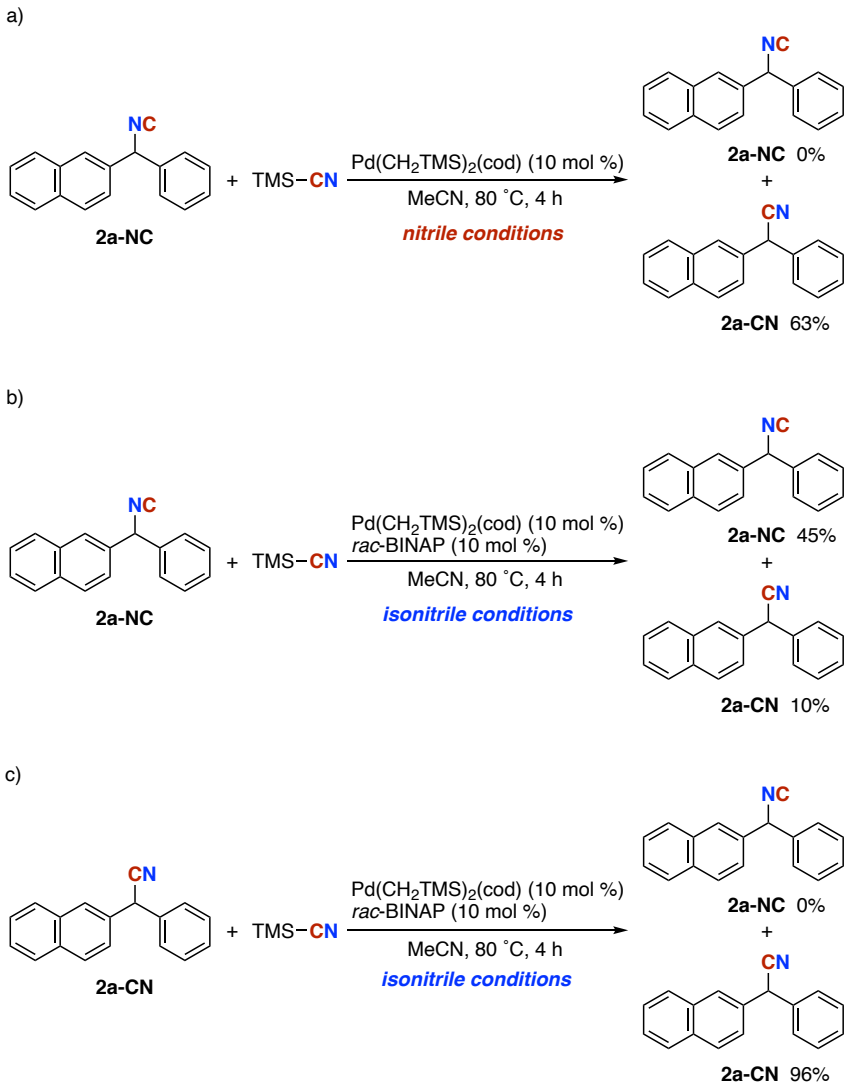


Figure 1. Reaction progresses under (a) isonitrile conditions and (b) nitrile conditions monitored by ^{1}H NMR.

Scheme 3. Attempt to Isomerize Isonitrile 2a-NC into Nitrile 2a-CN and Nitrile 2a-CN into Isonitrile 2a-NC; (a) Attempt to Isomerize Isonitrile 2a-NC into Nitrile 2a-CN under Nitrile Conditions; (b) Attempt to Isomerize Isonitrile 2a-NC into Nitrile 2a-CN under Isonitrile Conditions; (c) Attempt to Isomerize Nitrile 2a-CN into Isonitrile 2a-NC under Isonitrile Conditions



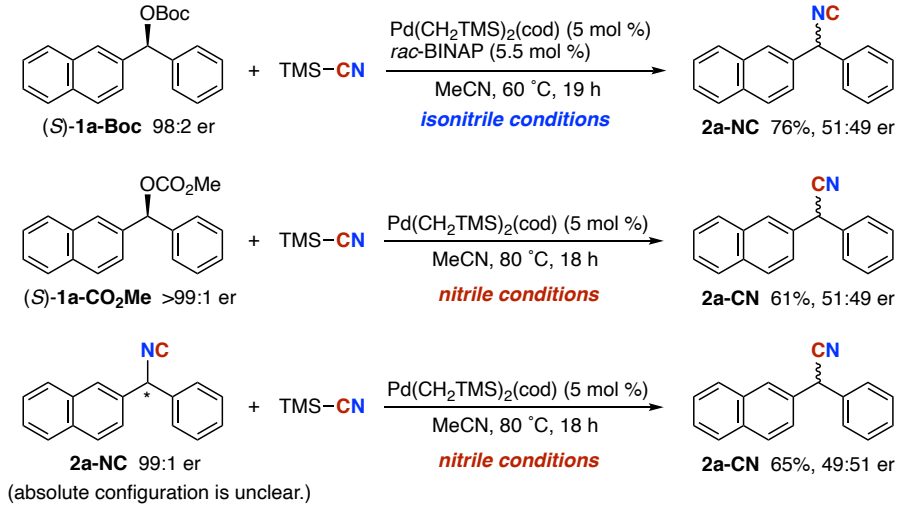
Additional information was obtained from the control experiments with optically active substrates (Scheme 4a). If the reaction proceeds via a Pd(0)/Pd(II) redox process involving a σ- or π-

benzylpalladium intermediate,[12] the stereochemical information should be transferred to the products to some extent.[9b,d-h,12c,f] On the other hand, if the reaction includes free benzylic cation species,[6d,g,7a,e-g] the corresponding racemates could be formed. Upon treatment of enantioenriched (*S*)-**1a-Boc** and (*S*)-**1a-CO_2Me** under the isonitrile and nitrile conditions, respectively, the corresponding isonitrile **2a-NC** and nitrile **2a-CN** were obtained in the complete racemic forms. Additionally, the independently prepared optically active isonitrile **2a-NC** was also isomerized to nitrile **2a-CN** with the almost complete racemization. These outcomes are suggestive of the free benzyl cation intermediates rather than the benzylpalladium ones under both the isonitrile and nitrile conditions.[13] The lower conversion of CF_3-substituted substrates **1d-Boc** and **1d-CO_2Me** (Scheme 2) is also consistent with the cation-mediated mechanism. Actually, the negative slope of $\rho = -1.8$ was obtained from the Hammet plot with σ_p for the conversion (in 20 min) of some *para*-substituted substrates **1-Boc** under the isonitrile conditions (Figure 2).[14] Additional experiments with the methally-containing substrate **1r-Boc** can further support the benzyl cation intermediacy (Scheme 4b): only a mixture of 6-endo cyclized olefinic products was observed. The corresponding 5-exo cyclized products and/or directly substituted products at the benzylic position were not detected at all.

Our another concern is connected with the active palladium species generated in situ. In the recent work on the related palladium-catalyzed isocyanation of allylic phosphates with TMSCN by Yurino and Ohkuma, the reaction of Pd salts with TMSCN immediately furnishes the corresponding $Pd(CN)_2$ and their ate-type complexes such as $(TMS)_n[Pd(CN)_{2+n}]$.[6f] Thus, we checked the reactivity of $Pd(CN)_2$ (Scheme 4c). A stoichiometric reaction of **1a-Boc** with $Pd(CN)_2$ and *rac*-BINAP just decomposed **1a-Boc**, and neither **2a-NC** nor **2a-CN** was detected. Similarly, any substituted products were not formed from **1a-CO_2Me** and $Pd(CN)_2$ in the absence of *rac*-BINAP. On the other hand, $Pd(CN)_2$ could replace $Pd(CH_2TMS)_2(cod)$ to catalyze the reaction with TMSCN under both the isonitrile and nitrile conditions, albeit with somewhat lower efficiency and isonitrile/nitrile selectivity. Thus, $Pd(CN)_2$ and/or its related species can be involved also in our reaction systems.

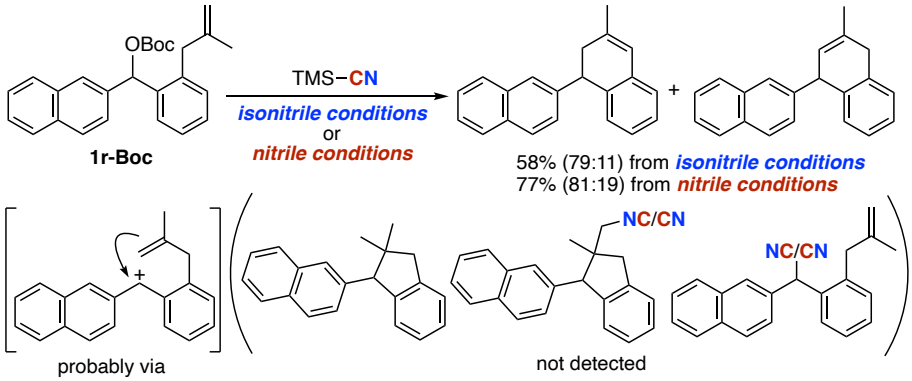
Scheme 4. Mechanistic Investigations; (a) Reactions of Optically Active Substrates; (b) Reactions of the Methally-containing Substrate 1r-Boc; (c) Attempts to Apply $Pd(CN)_2$

a)



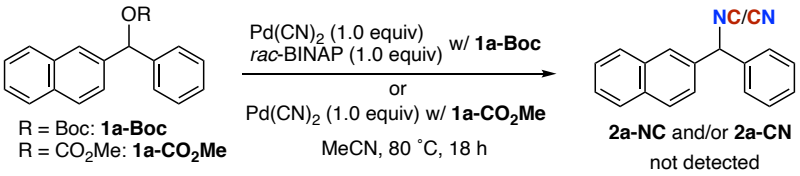
(absolute configuration is unclear.)

b)

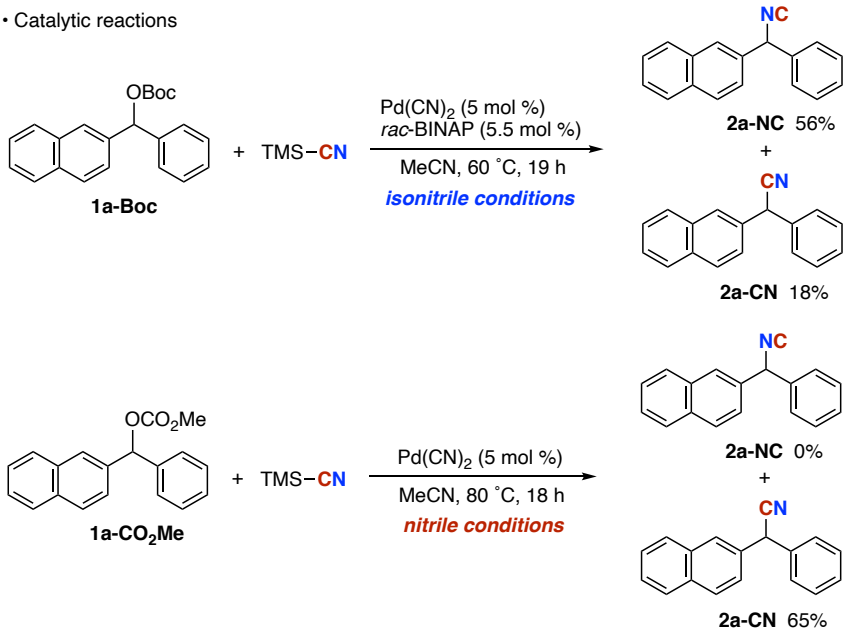


c)

• Stoichiometric reactions without TMSCN



• Catalytic reactions



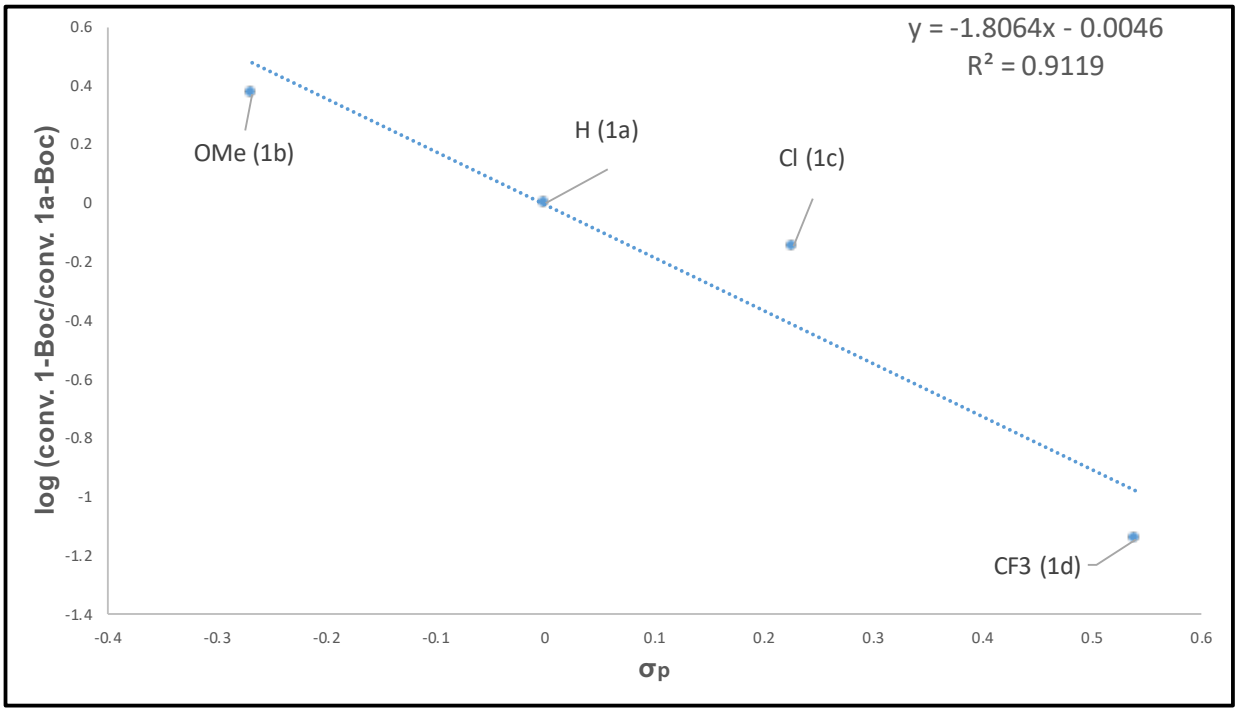
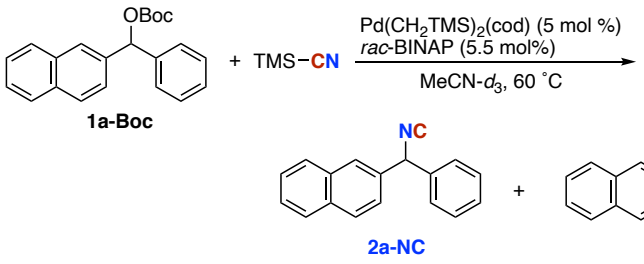
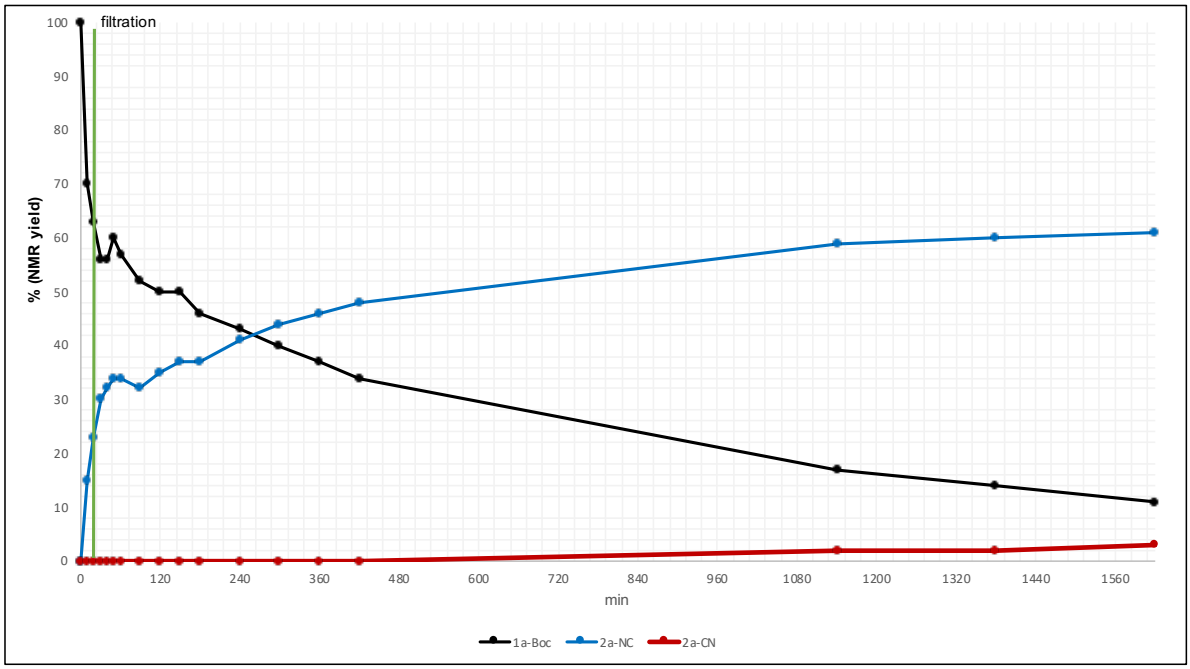


Figure 2. Hammet plot of *para*-substituted **1-Boc** under isonitrile conditions.

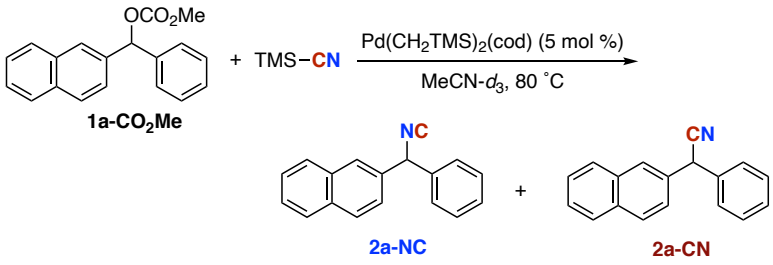
Finally, to clarify whether the reaction systems were homogeneous or heterogeneous, we performed the hot filtration test (Figure 3). Under the isonitrile conditions, we monitored the successful initial reaction progress, and then, the solution was filtered through a pad of Celite in 20 min. Further monitoring the resulting filtrate revealed that the reaction proceeded to convert **1a-Boc** to **1a-NC** (Figure 3a). On the other hand, under the nitrile conditions the conversion of starting **1a-CO_2Me** was completely shut down after hot filtration in 11 min (Figure 3b). These outcomes suggest that the isonitrile conditions using the *rac*-BINAP phosphine ligand involve the homogeneous palladium catalyst, while some heterogeneous palladium species are generated under the phosphine-free nitrile conditions.

a) isonitrile conditions





b) nitrile conditions



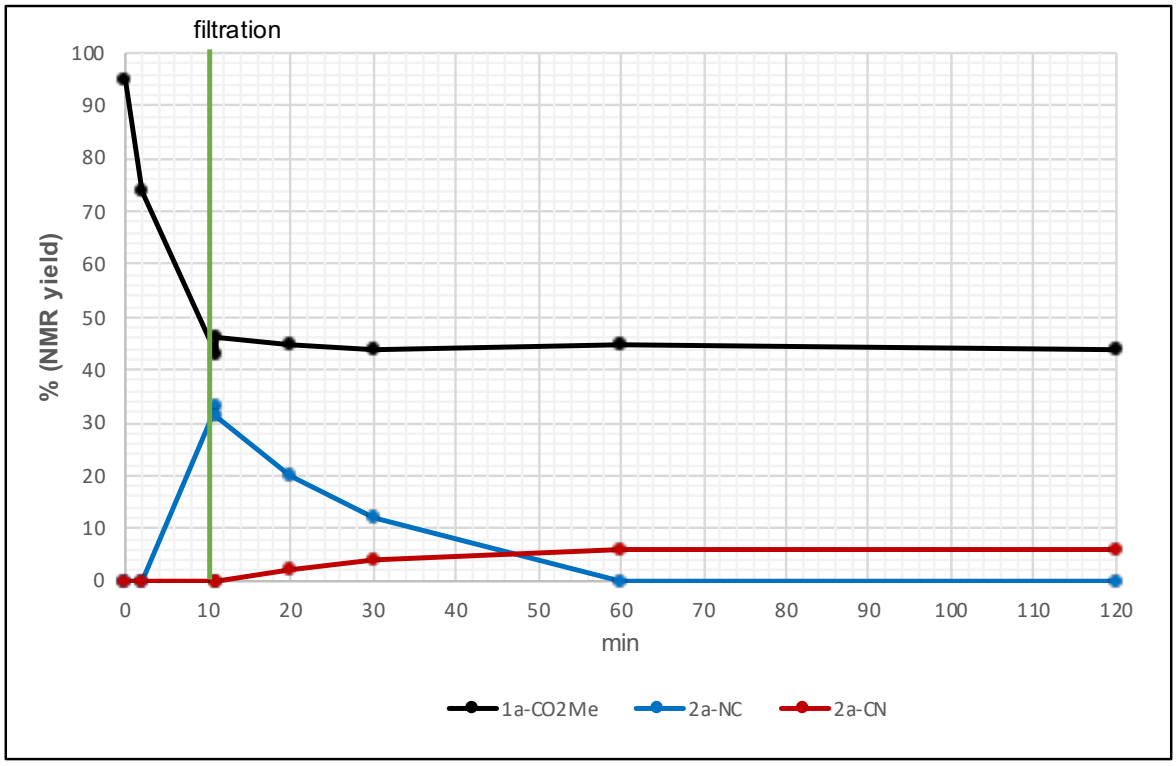


Figure 3. Hot filtration tests under (a) isonitrile conditions and (b) nitrile conditions monitored by ^{1}H NMR.

Conclusions

We have developed ligand-controlled palladium-catalyzed divergent synthesis of isonitriles and nitriles from readily available benzyl carbonates and TMSCN. Under the bisphosphine-ligated homogeneous Pd catalysis, the corresponding benzylic isonitriles are selectively formed. On the other hand, without external phosphine ligands the more electrophilic heterogeneous Pd species is formed, and the initially formed benzylic isonitriles are isomerized into the regioisomeric benzyl nitriles with high efficiency and selectivity. Thus, by the simple modification of ancillary ligands, both isonitriles and nitriles of high synthetic values can be obtained from the single diarylmethanol derivatives. Further mechanistic studies[15] and development of related stereoselective palladium catalysts are ongoing in our laboratory.

Experimental Section

Instrumentation and Chemicals ^{1}H, $^{13}C\{^{1}H\}$, and $^{19}F\{^{1}H\}$NMR spectra were recorded at 400, 100, and 376 MHz, respectively, for $CDCl_3$ solutions. HRMS data were obtained by electron ionization (EI) using a magnetic sector. TLC analyses were performed on commercial glass plates bearing a 0.25 mm layer of Merck silica gel $60F_{254}$. Silica gel (60 N, spherical neutral, Kanto Chemical Co.) was used for column chromatography. Gel permeation chromatography (GPC) was performed by LC-20AR (pump, SHIMADZU, 7.5 mL/min ethyl acetate) and SPD-20A (UV detector, SHIMADZU, 254 nm) with two in-line YMC-GPC T2000 (20 x 600 mm, particle size: 10 μm) (preparative columns, YMC).

Unless otherwise noted, materials obtained from commercial suppliers were used without further purification. MeCN was dried on a glass contour solvent dispensing system (Nikko Hansen & Co., Ltd.) prior to use. $Pd(CH_2TMS)_2(cod)$ was prepared according to the literature.[16] All *tert*-butyl and methyl carbonates **1** were synthesized from the corresponding carbinols.[9] The enantioenriched **2a-NC** (Scheme 4a) was obtained by optical resolution of racemic **2a-NC** with a preparative chiral HPLC (CHIRAL ART Cellulose-SJ (YMC), hexane/$CHCl_3$ = 9:1, 9.45 mL/min, UV detection at 250 nm, 25 ˚C). All reactions were carried out under nitrogen atmosphere unless otherwise noted.

Typical Procedure for Synthesis of Isonitriles 2-NC by Pd-Catalyzed Benzylic Substitution of *tert*-Butyl Diarylmethyl Carbonates 1-Boc with TMSCN. The synthesis of **2a-NC** (0.20 mmol scale) is representative (Scheme 2). [Pd($CH_2TMS)_2$(cod)] (3.9 mg, 0.010 mmol) and *rac*-BINAP (6.9 mg, 0.011 mmol) were placed in a Schlenk tube in a glovebox filled with nitrogen. MeCN (0.5 mL) was added to the reaction tube, and the suspension was stirred for 10 min. A solution of TMSCN (79.4 mg, 0.80 mmol) in MeCN (1.0 mL) was added to the suspension. The reaction tube was sealed with a septum and taken out of the glovebox. *tert*-Butyl (naphthalen-2-yl(phenyl)methyl) carbonate (**1a-Boc**; 66.9 mg, 0.20 mmol) was then added to the reaction tube. The suspension was stirred for 19 h at 60 °C (oil bath). The resulting mixture was filtered through a short pad of activated alumina and sodium sulfate, and the filtrate was concentrated in vacuo. 1-Methylnaphthalene (13.5 mg) was added as an internal standard, and the resulting mixture was analyzed by ^{1}H NMR in $CDCl_3$ solution. Concentration in vacuo and subsequent purification by column chromatography on neutral silica gel with hexane/ethyl acetate (20/1) as an eluent gave 2-(isocyano(phenyl)methyl)naphthalene (**2a-NC**, 38 mg, 0.15 mmol) in 77% yield.

1.0 mmol Scale Synthesis of 2a-NC. [Pd($CH_2TMS)_2$(cod)] (19.5 mg, 0.050 mmol) and *rac*-BINAP (34.1 mg, 0.055 mmol) were placed in a Schlenk tube in a glovebox filled with nitrogen. MeCN (2.5 mL) was added to the reaction tube, and the suspension was stirred for 10 min. A solution of TMSCN (396.6 mg, 4.0 mmol) in MeCN (5.0 mL) was added to the suspension. The reaction tube was sealed with a septum and taken out of the glovebox. *tert*-Butyl (naphthalen-2-yl(phenyl)methyl) carbonate (**1a-Boc**; 334.2 mg, 1.0 mmol) was then added to the reaction tube. The suspension was stirred for 19 h at 60 °C (oil bath). The resulting mixture was filtered through a short pad of activated alumina and sodium sulfate, and the filtrate was concentrated in vacuo. 1-Methylnaphthalene (14.8 mg) was added as an internal standard, and the resulting mixture was analyzed by ^{1}H NMR in $CDCl_3$ solution. Concentration in vacuo and subsequent purification by column chromatography on neutral silica gel with hexane/ethyl acetate (20/1) as an eluent gave 2-(isocyano(phenyl)methyl)naphthalene (**2a-NC**, 171 mg, 0.70 mmol) in 70% yield.

2-(Isocyano(phenyl)methyl)naphthalene (2a-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 38 mg (77%, 0.20 mmol scale); pale yellow solid; mp 73.0-74.0 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.89-7.82 (m, 4H), 7.55-7.49 (m, 2H), 7.42-7.32 (m, 6H), 6.07 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.6, 137.5, 134.8, 133.08, 133.03, 129.1, 129.0, 128.6, 128.2, 127.8, 126.80, 126.76 (overlapping, 2C), 125.6, 124.1, 62.2 (t, J = 6.1 Hz). HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{13}N$, 243.1043; found, 243.1048.

2-(Isocyano(4-methoxyphenyl)methyl)naphthalene (2b-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 34 mg (62%, 0.20 mmol scale); white solid; mp 128.2-129.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.88-7.82 (m, 4H), 7.55-7.49 (m, 2H), 7.35 (dd, J = 8.6, 1.9 Hz, 1H), 7.32-7.28 (m, 2H), 6.92-6.88 (m, 2H), 6.03 (s, 1H), 3.80 (s, 3H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.7, 158.1, 135.0, 133.1, 133.0, 129.7, 129.0, 128.2, 128.1, 127.7, 126.8, 126.7, 125.4, 124.1, 114.3, 61.6, 55.4. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1155.

2-((4-Chlorophenyl)(isocyano)methyl)naphthalene (2c-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 30 mg (55%, 0.20 mmol scale); red brown solid; mp 71.9-72.9 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.89-7.82 (m, 4H), 7.57-7.50 (m, 2H), 7.38-7.32 (m, 5H), 6.04 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.1, 136.0, 134.6, 134.2, 133.1, 133.0, 129.3, 129.2, 128.2 (overlapping, 2C), 127.8, 126.9 (overlapping, 2C), 125.7, 123.9, 61.5. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{12}ClN$, 277.0653; found, 277.0661.

2-(Isocyano(4-(trifluoromethyl)phenyl)methyl)naphthalene (2d-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 13 mg (21%, 0.20 mmol scale); red brown oil; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.88-7.84 (m, 4H), 7.66 (d, J = 8.2 Hz, 2H), 7.57-7.52 (m, 4H), 7.35

(dd, J = 8.6, 1.9 Hz, 1H), 6.12 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.7, 141.1, 133.9, 133.2, 133.0, 131.0 (q, J = 32.7 Hz), 129.4, 128.2, 127.8, 127.13, 127.05, 127.02, 126.1 (q, J = 3.7 Hz), 125.9, 123.81 (q, J = 270.1 Hz), 123.78, 61.7. $^{19}F\{^1H\}$ NMR ($CDCl_3$, 376 MHz): δ -62.72 (s). HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{12}F_3N$, 311.0916; found, 311.0926.

2-(Isocyano(*o*-tolyl)methyl)naphthalene (2e-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v) and then by GPC (ethyl acetate): 27 mg (53%, 0.20 mmol scale); yellow solid; mp 61.3-62.3 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.85-7.82 (m, 4H), 7.54-7.50 (m, 2H), 7.44-7.42 (m, 1H), 7.34 (dd, J = 8.6, 1.9 Hz, 1H), 7.32-7.27 (m, 2H), 7.23-7.21 (m, 1H), 6.24 (s, 1H), 2.33 (s, 3H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.2, 135.5, 135.2, 133.8, 133.1, 133.0, 131.2, 128.9, 128.8, 128.2, 127.7, 127.6, 126.8, 126.7 (overlapping, 2C), 125.9, 124.4, 59.5, 19.4. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}N$, 257.1199; found, 257.1204.

2-(Isocyano(3-methoxyphenyl)methyl)naphthalene (2f-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 29 mg (53%, 0.20 mmol scale); pale yellow oil; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.89-7.82 (m, 4H), 7.55-7.49 (m, 2H), 7.38 (dd, J = 8.6, 1.9 Hz, 1H), 7.30 (t, J = 8.0 Hz, 1H), 6.98 (d, J = 7.6 Hz, 1H), 6.95-6.94 (m, 1H), 6.87 (dd, J = 8.1, 2.6 Hz, 1H), 6.03 (s, 1H), 3.79 (s, 3H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 160.4, 158.6, 138.9, 134.7, 133.1, 133.0, 130.1, 129.1, 128.2, 127.7, 126.77, 126.75, 125.6, 124.1, 119.1, 113.8, 112.6, 62.1, 55.4. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1152.

2-(Isocyano(naphthalen-2-yl)methyl)thiophene (2g-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 24 mg (48%, 0.20 mmol scale); red brown solid; mp 48.9-50.9 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.95 (s, 1H), 7.90-7.85 (m, 3H), 7.57-7.52 (m, 2H), 7.47 (dd, J = 8.6, 1.9 Hz, 1H), 7.31 (dd, J = 5.1, 1.3 Hz, 1H), 7.08-7.06 (m, 1H), 6.97 (dd, J = 5.1, 3.6 Hz, 1H),

6.29 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.8, 141.0, 134.2, 133.3, 133.0, 129.2, 128.3, 127.8, 126.93 (overlapping, 2C), 126.88, 126.8, 126.5, 125.4, 123.8, 57.8. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NS$, 249.0607; found, 249.0610.

2-(Isocyano(phenyl)methyl)-6-methoxynaphthalene (2h-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 35 mg (63%, 0.20 mmol scale); white solid; mp 144.6-145.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.79-7.72 (m, 3H), 7.42-7.31 (m, 6H), 7.18 (dd, J = 8.9, 2.6 Hz, 1H), 7.12 (d, J = 2.4 Hz, 1H), 6.04 (s, 1H), 3.92 (s, 3H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.3 (overlapping, 2C), 137.6, 134.3, 132.6, 129.6, 129.0, 128.48, 128.46, 127.9, 126.7, 125.5, 124.7, 119.6, 105.7, 62.1, 55.4 (d, J = 2.1 Hz). HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1153.

1-(Isocyano(phenyl)methyl)naphthalene (2i-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 31 mg (64%, 0.20 mmol scale); pale yellow oil; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.93-7.86 (m, 3H), 7.62 (d, J = 6.9 Hz, 1H), 7.54-7.47 (m, 3H), 7.41-7.31 (m, 5H), 6.62 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.7, 136.9, 134.0, 132.3, 129.8, 129.7, 129.1, 129.0, 128.5, 126.94, 126.92, 126.1, 126.0, 125.3, 123.0, 59.5. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{13}N$, 243.1043; found, 243.1046.

9-(Isocyano(phenyl)methyl)phenanthrene (2j-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 29 mg (49%, 0.20 mmol scale); white solid; mp 123.7-124.7 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 8.76 (d, J = 8.2 Hz, 1H), 8.69 (d, J = 8.2 Hz, 1H), 7.95-7.93 (m, 2H), 7.87 (d, J = 7.5 Hz, 1H), 7.74-7.63 (m, 3H), 7.58-7.54 (m, 1H), 7.46-7.43 (m, 2H), 7.40-7.34 (m, 3H), 6.63 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.1, 136.7, 131.1, 130.8, 130.7, 130.4,

129.2, 129.1, 128.7, 128.5, 127.7, 127.3, 127.2, 127.14, 127.08, 126.9, 124.1, 123.5, 122.6, 60.1. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{22}H_{15}N$, 293.1199; found, 293.1201.

2-(Isocyano(phenyl)methyl)benzo[*b*]thiophene (2k-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 28 mg (56%, 0.20 mmol scale); pale yellow solid; mp 94.9-95.9 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.77-7.73 (m, 2H), 7.49-7.40 (m, 5H), 7.38-7.30 (m, 2H), 7.29 (s, 1H), 6.17 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.3, 141.4, 140.1, 138.8, 136.4, 129.17, 129.15, 126.5, 125.1, 124.8, 124.1, 122.9, 122.4, 58.3. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NS$, 249.0607; found, 249.0610.

2-(Isocyano(phenyl)methyl)benzofuran (2l-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 28 mg (61%, 0.20 mmol scale); pale yellow solid; mp 62.1-63.1 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.54 (d, J = 7.7 Hz, 1H), 7.51-7.48 (m, 2H), 7.46-7.40 (m, 4H), 7.30 (td, J = 7.8, 1.3 Hz, 1H), 7.23 (td, J = 7.5, 1.0 Hz, 1H), 6.65 (t, J = 0.9 Hz, 1H), 6.05 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 159.5, 155.4, 152.1, 134.1, 129.2, 129.1, 127.5, 126.8, 125.1, 123.3, 121.4, 111.5, 105.3, 56.3. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NO$, 233.0835; found, 233.0841.

2-(Isocyano(phenyl)methyl)dibenzo[*b*,*d*]thiophene (2m-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 36 mg (61%, 0.20 mmol scale); pale yellow solid; mp 128.9-129.9 °C; ^1H NMR ($CDCl_3$, 400 MHz): δ 8.19-8.14 (m, 2H), 7.88-7.84 (m, 2H), 7.51-7.45 (m, 2H), 7.44-7.33 (m, 6H), 6.10 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.7, 140.1, 139.7, 137.7, 136.1, 135.1, 134.2, 129.2, 128.7, 127.3, 126.8, 125.3, 124.7, 123.5, 123.0, 121.9, 119.7, 62.1. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{20}H_{13}NS$, 299.0763; found, 299.0764.

4-(Isocyano(phenyl)methyl)-1,1'-biphenyl (2n-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 40 mg (74%, 0.20 mmol scale); yellow solid; mp

112.6-113.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.61-7.55 (m, 4H), 7.46-7.33 (m, 10H), 5.95 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.4, 141.5, 140.2, 137.5, 136.5, 129.1, 128.9, 128.6, 127.72, 127.68, 127.1, 127.0, 126.6, 61.8. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{20}H_{15}N$, 269.1199; found, 269.1204.

(Isocyanomethylene)dibenzene (2o-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v) and then by GPC (ethyl acetate): 16 mg (41%, 0.20 mmol scale); colorless oil; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.41-7.31 (m, 10H), 5.91 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.3, 137.6, 129.0, 128.5, 126.6, 62.0 (t, J = 6.5 Hz). HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{14}H_{11}N$, 193.0886; found, 193.0892.

2-(1-Isocyanoethyl)naphthalene (2p-NC). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 6 mg (17%, 0.20 mmol scale); pale yellow solid; mp 64.1-65.1 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.90-7.84 (m, 4H), 7.55-7.49 (m, 2H), 7.45 (dd, J = 8.6, 1.9 Hz, 1H), 5.00 (q, J = 6.6 Hz, 1H), 1.77 (dt, J = 6.9, 2.2 Hz, 3H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 156.5, 135.8, 133.2, 133.0, 129.0, 128.0, 127.7, 126.7, 126.5, 124.4, 123.1, 54.0 (t, J = 6.2 Hz), 25.1. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{13}H_{11}N$, 181.0886; found, 181.0889.

Typical Procedure for Synthesis of Nitriles 2-CN by Pd-Catalyzed Benzylic Substitution of Diarylmethyl Methyl Carbonates 1-CO_2Me with TMSCN. The synthesis of **2a-CN** (0.20 mmol scale) is representative (Scheme 2). [Pd(CH_2TMS)$_2$(cod)] (3.7 mg, 0.009 mmol) was placed in a Schlenk tube in a glovebox filled with nitrogen. MeCN (0.5 mL) was added to the reaction tube, and the suspension was stirred for 10 min. A solution of TMSCN (29.7 mg, 0.30 mmol) in MeCN (1.0 mL) was added to the suspension. The reaction tube was sealed with a septum and taken out of the glovebox. Methyl (naphthalen-2-yl(phenyl)methyl) carbonate (**1a-CO_2Me**; 58.7 mg, 0.20 mmol) was then added to the reaction tube. The suspension was stirred for 18 h at 80 °C (oil bath). The resulting mixture was

filtered through a short pad of activated alumina and sodium sulfate, and the filtrate was concentrated in vacuo. 1-Methylnaphthalene (12.1 mg) was added as an internal standard, and the resulting mixture was analyzed by ^{1}H NMR in $CDCl_3$ solution. Concentration in vacuo and subsequent purification by column chromatography on neutral silica gel with hexane/ethyl acetate (20/1) as an eluent gave 2-(naphthalen-2-yl)-2-phenylacetonitrile (**2a-CN**, 35 mg, 0.14 mmol) in 71% yield.

1.0 mmol Scale Synthesis of 2a-CN. [$Pd(CH_2TMS)_2(cod)$] (7.7 mg, 0.020 mmol) was placed in a Schlenk tube in a glovebox filled with nitrogen. MeCN (2.5 mL) was added to the reaction tube, and the suspension was stirred for 10 min. A solution of TMSCN (148.9 mg, 1.5 mmol) in MeCN (5.0 mL) was added to the suspension. The reaction tube was sealed with a septum and taken out of the glovebox. Methyl (naphthalen-2-yl(phenyl)methyl) carbonate (**1a-CO_2Me**; 292.3 mg, 1.0 mmol) was then added to the reaction tube. The suspension was stirred for 18 h at 80 °C (oil bath). The resulting mixture was filtered through a short pad of activated alumina and sodium sulfate, and the filtrate was concentrated in vacuo. 1-Methylnaphthalene (13.6 mg) was added as an internal standard, and the resulting mixture was analyzed by ^{1}H NMR in $CDCl_3$ solution. After evaporation, purification of the residual solid by column chromatography on neutral silica gel with hexane/ethyl acetate (20/1) and subsequent GPC (ethyl acetate) gave 2-(naphthalen-2-yl)-2-phenylacetonitrile (**2a-CN**, 176 mg, 0.72 mmol) in 72% yield.

2-(Naphthalen-2-yl)-2-phenylacetonitrile (2a-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 35 mg (71%, 0.20 mmol scale); pale yellow solid; mp 76.5-77.5 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.89-7.89 (m, 1H), 7.86-7.82 (m, 3H), 7.55-7.49 (m, 2H), 7.41-7.31 (m, 6H), 5.31 (s, 1H). $^{13}C\{^1H\}$ NMR ($CDCl_3$, 100 MHz): δ 135.8, 133.3, 133.1, 132.8, 129.3 (overlapping, 2C), 128.3, 128.0, 127.9, 127.7, 126.8, 126.73, 126.72, 125.2, 119.6, 42.8. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{13}N$, 243.1043; found, 243.1045.

2-(4-Methoxyphenyl)-2-(naphthalen-2-yl)acetonitrile (2b-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (10/1, v/v): 50 mg (91%, 0.20 mmol scale); white solid; mp 136.2-137.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.88-7.81 (m, 4H), 7.55-7.48 (m, 2H), 7.35 (dd, J = 8.6, 1.9 Hz, 1H), 7.31-7.27 (m, 2H), 6.91-6.88 (m, 2H), 5.26 (s, 1H), 3.80 (s, 3H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 159.5, 133.4,, 42.0, 133.2, 132.8, 129.2, 129.1, 128.0, 127.8, 127.7, 126.8, 126.6, 126.5, 125.2, 119.9, 114.6, 55.4. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1150.

2-(4-Chlorophenyl)-2-(naphthalen-2-yl)acetonitrile (2c-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 36 mg (64%, 0.20 mmol scale); pale orange solid; mp 71.9-72.9 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.86-7.83 (m, 4H), 7.56-7.52 (m, 2H), 7.37-7.32 (m, 5H), 5.28 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 134.5, 134.3, 133.2, 132.9, 132.5, 129.4 (overlapping, 2C), 129.2, 128.0, 127.8, 127.0, 126.9, 126.8, 125.0, 119.2, 42.2. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{12}ClN$, 277.0653; found, 277.0661.

2-(Naphthalen-2-yl)-2-(4-(trifluoromethyl)phenyl)acetonitrile (2d-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v) and then by GPC (ethyl acetate): 13 mg (21%, 0.20 mmol scale); yellow solid; mp 76.6-77.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.89-7.83 (m, 4H), 7.65 (d, J = 8.2 Hz, 2H), 7.57-7.52 (m, 4H), 7.34 (dd, J = 8.6, 2.0 Hz, 1H), 5.36 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 139.7, 133.2, 132.9, 132.1, 130.8 (q, J = 32.2 Hz), 129.6, 128.3, 128.0, 127.8, 127.1, 127.0, 126.9, 126.3 (q, J = 3.7 Hz), 124.9, 123.7 (q, J = 270.7 Hz), 118.9, 42.6. ^{19}F{^{1}H} NMR ($CDCl_3$, 376 MHz): δ -62.75 (s). HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{12}F_3N$, 311.0916; found, 311.0926.

2-(Naphthalen-2-yl)-2-(*o*-tolyl)acetonitrile (2e-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 33 mg (63%, 0.20 mmol scale); orange solid; mp 99.6-100.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.84-7.81 (m, 4H), 7.53-7.49 (m, 2H), 7.42-7.39 (m, 1H),

7.32 (dd, J = 8.6, 1.8 Hz, 1H), 7.29-7.26 (m, 2H), 7.24-7.22 (m, 1H), 5.46 (s, 1H), 2.33 (s, 3H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 136.1, 133.6, 133.2, 132.8, 132.2, 131.3, 129.1, 128.9, 128.7, 128.0, 127.7, 126.91, 126.85, 126.77, 126.67, 125.3, 119.5, 40.1, 19.6. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}N$, 257.1199; found, 257.1200.

2-(3-Methoxyphenyl)-2-(naphthalen-2-yl)acetonitrile (2f-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (10/1, v/v) and then by GPC (ethyl acetate): 26 mg (48%, 0.20 mmol scale); pale yellow oil; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.89 (s, 1H), 7.86-7.82 (m, 3H), 7.55-7.49 (m, 2H), 7.37 (dd, J = 8.6, 1.9 Hz, 1H), 7.29 (t, J = 8.0 Hz, 1H), 6.98 (d, J = 7.7 Hz, 1H), 6.92-6.91 (m, 1H), 6.86 (dd, J = 8.2, 2.5 Hz, 1H), 5.27 (s, 1H), 3.79 (s, 3H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 160.2, 137.2, 133.3, 133.0, 132.8, 130.3, 129.3, 128.0, 127.7, 126.8, 126.7 (overlapping, 2C), 125.2, 120.2, 119.6, 113.8, 113.6, 55.4, 42.7. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1151.

2-(Naphthalen-2-yl)-2-(thiophen-2-yl)acetonitrile (2g-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 24 mg (47%, 0.20 mmol scale); yellow solid; mp 50.2-51.2 ^{o}C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.94 (s, 1H), 7.89-7.84 (m, 3H), 7.57-7.51 (m, 2H), 7.45 (dd, J = 8.6, 2.0 Hz, 1H), 7.29 (dd, J = 5.2, 1.2 Hz, 1H), 7.14-7.12 (m, 1H), 6.99 (dd, J = 5.2, 3.6 Hz, 1H), 5.53 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 138.5, 133.2, 133.1, 132.6, 129.4, 128.1, 127.8, 127.2, 126.92 (overlapping, 2C), 126.91, 126.7, 126.6, 124.9, 118.8, 38.2. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NS$, 249.0607; found, 249.0611.

2-(6-Methoxynaphthalen-2-yl)-2-phenylacetonitrile (2h-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (10/1, v/v): 38 mg (70%, 0.20 mmol scale); white solid; mp 168.6-169.6 ^{o}C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.79 (s, 1H), 7.74 (d, J = 5.2 Hz, 1H), 7.72 (d, J = 4.8 Hz, 1H), 7.40-7.31 (m, 6H), 7.18 (dd, J = 9.0, 2.6 Hz, 1H), 7.12 (d, J = 2.4 Hz, 1H), 5.27 (s, 1H), 3.92 (s, 3H).

$^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 158.3, 136.0, 134.1, 130.8, 129.5, 129.2, 128.7, 128.3, 128.0, 127.8, 126.5, 125.8, 119.8, 119.6, 105.7, 55.4, 42.6. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{19}H_{15}NO$, 273.1148; found, 273.1155.

2-(Naphthalen-1-yl)-2-phenylacetonitrile (2i-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (10/1, v/v): 33 mg (68%, 0.20 mmol scale); pale yellow solid; mp 90.6-91.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.92-7.87 (m, 3H), 7.64 (d, J = 6.8 Hz, 1H), 7.53-7.49 (m, 3H), 5.83 (s, 1H), 7.38-7.31 (m, 5H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 135.3, 134.2, 130.8, 130.3, 129.6, 129.21, 129.17, 128.3, 127.8, 127.2, 127.1, 126.3, 125.5, 123.1, 119.8, 39.9. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{18}H_{13}N$, 243.1043; found, 243.1048.

2-(Phenanthren-9-yl)-2-phenylacetonitrile (2j-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 50 mg (82%, 0.20 mmol scale); white solid; mp 61.8-62.8 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 8.76 (d, J = 8.2 Hz, 1H), 8.69 (d, J = 8.2 Hz, 1H), 7.97 (s, 1H), 5.86 (s, 1H), 7.94 (d, J = 7.8 Hz, 1H), 7.38-7.30 (m, 3H), 7.88 (d, J = 8.3 Hz, 1H), 7.74-7.63 (m, 3H), 7.59-7.54 (m, 1H), 7.43-7.40 (m, 2H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 135.0, 131.2, 130.9, 130.6, 129.3, 129.0, 128.95, 128.93, 128.5, 128.4, 127.9, 127.7, 127.23, 127.18, 127.0, 124.1, 123.6, 122.6, 119.7, 40.5. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{22}H_{15}N$, 293.1199; found, 293.1200.

2-(Benzo[*b*]thiophen-2-yl)-2-phenylacetonitrile (2k-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 37 mg (74%, 0.20 mmol scale); pale yellow solid; mp 92.6-93.6 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.74 (d, J = 8.0 Hz, 2H), 7.48-7.30 (m, 8H), 5.41 (s, 1H). $^{13}C\{^{1}H\}$ NMR ($CDCl_3$, 100 MHz): δ 140.1, 139.2, 139.0, 134.8, 129.4, 129.0, 127.7, 125.0, 124.8, 123.9, 123.4, 122.3, 118.4, 38.8. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NS$, 249.0607; found, 249.0610.

2-(Benzofuran-2-yl)-2-phenylacetonitrile (2l-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 36 mg (77%, 0.20 mmol scale); yellow solid; mp 75.9-76.9 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.54 (d, J = 7.6 Hz, 1H), 7.49-7.39 (m, 6H), 7.30 (td, J = 8.3, 1.4 Hz, 1H), 7.23 (td, J = 7.5, 1.0 Hz, 1H), 6.70 (t, J = 0.9 Hz, 1H), 5.33 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 155.4, 150.6, 132.4, 129.3, 129.0, 127.9, 127.6, 125.0, 123.3, 121.3, 117.2, 111.4, 105.5, 37.3. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{16}H_{11}NO$, 233.0835; found, 233.0839.

2-(Dibenzo[*b*,*d*]thiophen-2-yl)-2-phenylacetonitrile (2m-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 33 mg (55%, 0.20 mmol scale); pale yellow solid; mp 139.1–139.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 8.18-8.14 (m, 2H), 7.88-7.83 (m, 2H), 7.51-7.45 (m, 2H), 7.43-7.32 (m, 6H), 5.34 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 140.1, 139.5, 136.3, 136.1, 135.0, 132.4, 129.4, 128.5, 127.9, 127.4, 126.3, 124.7, 123.7, 123.0, 121.9, 120.8, 119.9, 42.7. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{20}H_{13}NS$, 299.0763; found, 299.0766.

2-([1,1'-Biphenyl]-4-yl)-2-phenylacetonitrile (2n-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 33 mg (60%, 0.20 mmol scale); yellow solid; mp 131.2-132.2 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.61-7.55 (m, 4H), 7.46-7.32 (m, 10H), 5.19 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 141.3, 140.2, 135.8, 134.8, 129.3, 128.9, 128.3, 128.2, 127.9, 127.8, 127.7, 127.1, 119.7, 42.3. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{20}H_{15}N$, 269.1199; found, 269.1201.

2,2-Diphenylacetonitrile (2o-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 23 mg (59%, 0.20 mmol scale); pale orange solid; mp 69.9-70.9 °C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.40-7.30 (m, 10H), 5.14 (s, 1H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 135.9, 129.2, 128.3, 127.7, 119.7, 42.6. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{14}H_{11}N$, 193.0886; found, 193.0888.

2-(Naphthalen-2-yl)acetonitrile (2q-CN). It was purified by silica gel column chromatography with hexane/ethyl acetate (20/1, v/v): 14 mg (42%, 0.20 mmol scale); pale yellow solid; mp 83.6-84.6 ºC; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.87-7.83 (m, 4H), 7.55-7.49 (m, 2H), 7.39 (dd, J = 8.4, 1.8 Hz, 1H), 3.92 (s, 2H). ^{13}C{^{1}H} NMR ($CDCl_3$, 100 MHz): δ 133.3, 132.7, 129.1, 127.8, 127.7, 127.2, 126.9, 126.8, 126.5, 125.5, 117.9, 23.9. HRMS (EI) *m/z*: $(M)^+$ calcd for $C_{12}H_9N$, 167.0723; found, 167.0733.

ASSOCIATED CONTENT

Supporting Information

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

^{1}H, ^{13}C{^{1}H}, and ^{19}F{^{1}H} NMR spectra for products, detailed optimization studies, and tentative reaction mechanism (PDF)

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