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Palladium-Catalyzed Carbonylation Reactions of Aryl Bromides at Atmospheric Pressure: A General System Based on Xantphos

Joseph R. Martinelli, **Donald A. Watson**, **Dominique M. M. Freckmann**, **Timothy E. Barder**, and **Stephen L. Buchwald***
Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Abstract

A method for the Pd-catalyzed carbonylation of aryl bromides has been developed using Xantphos as the ligand. This method is effective for the direct synthesis of Weinreb amides, 1° and 2° benzamides and methyl esters from the corresponding aryl bromides at atmospheric pressure. In addition, a putative catalytic intermediate, (Xanphos)Pd(Br)benzoyl, was prepared and an X-ray crystal structure was obtained revealing an unusual *cis*-coordination mode of Xantphos in this palladium-acyl complex.

Introduction

Carbon monoxide, CO, is a synthetically useful organic molecule and, due to its ability to act as a σ-donor and a π-acceptor, an excellent ligand for transition metals.[1] Chemists have long endeavored to utilize the unique reactivity of CO in the development of synthetic methods, and the success of these many workers is reflected by the myriad reports of highly efficient polymerization processes[2] and systems for catalytic carbonylation reactions.[3] The seminal report by Heck in 1974 details the first use of the palladium catalyzed three-component coupling reaction of an aryl halide, CO, and an alcohol or amine (more generally, a nucleophile).[4]

The palladium-catalyzed carbonylation reaction is a very convenient method for the regioselective synthesis of carbonyl-containing compounds. The utility of this class of transformations has spurred wide interest resulting in many excellent contributions. The scope of the processes that have been developed is wide and includes many nucleophiles, enabling the efficient syntheses of numerous carbonyl derivatives,[5] including ^{11}C radio-labeled compounds used for PET studies.[6] Other interesting advances include the use of ionic liquids[7] and various surrogates for CO,[8] such as DMF[8b] or $Mo(CO)_6$.[8c] Despite the importance of each individual contribution, the ligand and the pressure of CO employed often varies from one system to another making the development of a more general system a desirable goal.

In an effort to develop such a system, we chose three useful and representative carbonylation reactions: aminocarbonylation to form Weinreb amides, aminocarbonylation to form benzamides and alkoxycarbonylation to form methyl esters. Additionally, for convenience (on the academic laboratory scale), we focused on reactions conducted at atmospheric pressure to obviate the need for specialized high-pressure reaction vessels. In this paper, we disclose our

sbuchwal@mit.edu .

Supporting Information Available: Characterization data of each compound. This material is available free of charge via the Internet at http://pubs.acs.org.

efforts toward arriving at a general system for these Pd-catalyzed carbonylation processes using aryl bromides as substrates and Xantphos as the supporting ligand.

Results and Discussion

As reported in a recent communication,[5d] we began our efforts to develop a general system for Pd-catalyzed carbonylation procedure by examining the formation of the Weinreb amides derived from *para*-bromoanisole and dimethylhydroxylamine hydrochloride (Table 1). Although numerous variables associated with the reaction conditions were examined (including Pd precatalyst, base, and solvent), the most influential proved to be the choice of ligand. Previous studies have shown that ligands employed in carbonylation chemistry must be electron-donating enough to promote oxidative addition and prevent precipitation of Pd-black or formation of Pd-carbonyl clusters.[9] Additionally, bidentate ligands are often superior to mono-dentate ligands in these processes,[5a–e] a fact that has been ascribed to their greater ability to prevent catalyst poisoning via ligation of multiple CO ligands. Despite these guidelines, our initial efforts in this area, which examined a wide range of electron-rich mono- and bidentate- phosphine ligands, failed to provide detectable amounts of product (Table 1, Entries 1–7).

Xantphos, a bidentate ligand developed by van Leeuwen for the hydroformylation reaction, [10] has been used extensively for Pd-catalyzed C-N bond forming processes.[11] The wide bite angle (110°)[12] and flexibility range (97° – 133°)[12] characteristic of Xantphos are believed to impart a dynamic coordination environment that may be important for catalyst activity and stability in Pd- and other transition metal-catalyzed processes.[13]

Unlike other ligands examined, Xantphos provided a highly active catalyst, delivering significant amounts of product after only 2 hours under our screening conditions (Table 1, entry 8). This result is notable as both DPEphos and dppf, which are also bidentate ligands and have similar bite angles to Xantphos,[14] did not produce active catalysts and highlights the importance of the flexible coordination environment of the Xantphos backbone.

These initial screening experiments with Xantphos were conducted with a 1:1 ratio of ligand to $Pd(OAc)_2$, as the literature indicated that excess Xantphos can inhibit Pd-catalyzed C-N bond forming reactions.[15] Optimization of the reaction conditions using this Pd:L ratio revealed that the reaction was best conducted at 80 °C. At 100 °C incomplete conversion of the starting material was observed. We attribute this unusual result to increased catalyst stability at the lower temperatures.

Thus, under our optimized conditions - $Pd(OAc)_2$ (2 mol%), Xantphos (2mol%), Na_2CO_3 (3 equiv.), and N,O-dimethylhydroxylamine hydrochloride (1.5 equiv.) in toluene at 80 °C under 1 atmosphere of CO - a number of substituted aryl bromides were successfully transformed into the corresponding Weinreb amides (Table 1, entries 1–11).

One limitation of the method was in the use of *ortho*-substituted aryl bromides, which remained recalcitrant under the reaction conditions. However, re-optimization of the reaction parameters revealed that raising the reaction temperature and increasing the Xantphos to Pd ratio from 1:1 to 2:1 allowed for these more demanding substrates to be transformed into Weinreb amides in high yield (Table 1, entries 12–19). Additionally, K_3PO_4 proved more effective than Na_2CO_3 as base under these new conditions. It is evident that at the higher reaction temperatures required for the *ortho*-substituted substrates, excess ligand increases the stability of the catalyst system.

A number of functional groups were tolerated under either set of conditions, including a nitrile, nitro, aryl fluoride, aryl chloride, *tert*-butyl carbamate, methyl ester, ethylene glycol-protected

aldehyde, and trifluoromethyl group. Heteroaryl bromides, such as 2-bromo-3-methylpyridine and 3-bromothiophene, were also transformed to the corresponding Weinreb amides (Table 2, entries 4 and 18). Additionally, although unactivated aryl chlorides were unreactive, an activated aryl chloride, 4-chlorobenzonitrile, was also converted to product under these reaction conditions (Table 2, entry 21).

In addition to the formation of Weinreb amides, the conditions described proved extremely general for the atmospheric pressure aminocarbonylation of aryl bromides to produce other amides. Indeed, numerous 1°, cyclic and acyclic 2° amines and anilines could be employed under these conditions (Table 3). As in the synthesis of Weinreb amides, a number of functional groups were tolerated including nitriles, aryl chlorides, aryl fluorides, and methyl esters. Interestingly, if the methyl ester moiety in the substrate is *ortho* to the aryl bromide and a 1° amine was used, an *n*-alkyl phthalamide product was the exclusive product observed (Table 3, entries 15–17). Heteroaryl bromides, such as 3-bromopyridine and 3-bromoquinoline, were also converted into benzamides without complication (Table 3, entries 19 and 20).

The success of this method for the aminocarbonylation of aryl bromides at atmospheric pressure of CO suggested that this method could be expanded to include other nucleophiles, such as alcohols for the synthesis of esters. There have been some recent reports detailing very effective methods for the synthesis of methyl esters from aryl bromides,[5b] heteroaryl chlorides,[5b] activated aryl sulfonates,[16] and unactivated aryl mesylates and tosylates.[5c] However, all but two of these methods, which were recently developed in our labrotory,[5c,17] require pressures above 1 atm of CO and thus require the use of specialized equipment. This pressure limitation is also due, in part, to the use of methanol since its boiling point of 65 °C limits reaction temperatures at atmospheric pressure.

Initial attempts to apply the conditions utilized for the aminocarbonylation reactions previously described were plagued by formation of arene via unwanted reduction of the aryl bromide. During the optimization of the process, we discovered that this side reaction could be completely suppressed by replacing toluene solvent and the inorganic base with Et_3N. The Et_3N in this system not only acts as solvent and base but may also provide an efficient means for conversion of $Pd(OAc)_2$ to the active Pd(0) catalyst.[18]

This Xantphos-based catalyst system is capable of converting aryl bromides to the corresponding methyl esters at 70 °C under an atmosphere of CO. Though a 10-fold excess of methanol was employed, the conditions are suitably mild to allow the presence of various functional groups including, an ethyl ester (with no observable trans-esterification), aryl fluoride, nitrile, and tert-butyl carbamate. A heteroaryl bromide, 4-bromoisoquinoline, was also transformed to the corresponding methyl ester (Table 4, entry 6). Unfortunately, due to the low reaction temperatures, more challenging substrates remained recalcitrant. For example, exposing 2-cyclohexybromobenzene to these reaction conditions resulted in no detectable conversion of the starting aryl bromide or formation of the desired product. Despite this limitation, we believe this system represents the most general system to date for the atmospheric pressure amino- and alkoxycarbonylation of aryl bromides.

In an attempt to gain insight into the mechanism of these Pd-catalyzed transformations, we set out to prepare and isolate a Xantphos-coordinated Pd-acyl complex. Recrystallization of the material obtained from combining $Pd_2(dba)_3$, Xantphos, and benzoyl bromide provided the desired complex, which was demonstrated to be a chemically and kinetically competent catalyst for the carbonylation reaction.[19] The structure of the complex was determined by single crystal X-ray analysis (Figure 2). Interestingly, though the solution state structure for the complex was clearly the trans-coordinated isomer (as determined by the single resonance in the ^{31}P NMR spectrum), the solid-state structure contained the phosphines bound in a cis-

configuration. Although the coordinatively-flexible nature of the Xantphos framework has been previously discussed,[20] the cis-configuration of the complex in the solid state is somewhat unusual. Most neutral Xantphos-Pd(II) complexes containing aryl ligands have been shown to be trans-configured in the solid state.[20,21,22]

Though the discrete mechanistic underpinning of this coordinative flexibility remains unclear, we believe that it may play a critical role in the efficiency of this catalytic system. As pointed out by the Merck group in their work on BINAP-Pd catalyzed carbonylation of aryl bromides, [5b] previous mechanistic studies on carbonylation reactions of aryl halides have been performed on catalytic systems containing only monodentate-phosphines.[23] The mechanisms proposed in these studies often involve dissociative steps in which a mono-phosphine exits the coordination sphere of the metal to allow for binding of carbon monoxide or the nucleophile. As such dissociative mechanisms are expected to be less favorable (though not impossible) in systems containing bidentate ligands, it is not clear that systems involving bidentate ligands proceed in this way. It is possible that associative mechanisms may be involved, and the Merck group has suggested several possibilities. Unfortunately, no detailed mechanistic studies have yet been carried out on bidentate catalyst systems to make definitive arguments.

It is notable, however, that while the cis-chelating ligand BINAP is very effective for Pd-catalyzed carbonylation reactions, it requires CO pressures > 1atmosphere. On the other hand, the Xantphos system reacts rapidly at 1 atm. We think that it is reasonable to suggest that greater efficiency of the Xantphos system might arise from the greater flexibility of the ligand system. We believe that Xantphos more readily disassociates of one of its phosphine groups, making dissociative pathways more accessible than for BINAP. Alternatively, if the bidentate systems are proceeding exclusively via associative mechanisms, it is possible that the configuration with trans-phosphines provides a lower energy pathway than the cis configuration, which is a pathway that is not possible using BINAP. While this discussion is speculative, at present we favor the former (dissociative) pathway.

Conclusion

In summary, we have described the development of a Pd-catalyzed carbonylation protocol employing Xantphos as the ligand. This method has been demonstrated to be effective for the direct synthesis of Weinreb amides, benzamides and methyl esters from the corresponding aryl bromides at atmospheric pressure. In addition, a putative catalytic intermediate, (Xantphos)Pd(Br)benzoyl, was synthesized and an X-ray crystal structure was obtained. This crystal structure revealed that this species possesses, in contrast to the majority of Pd-aryl complexes ligated by Xantphos, a cis-coordinated palladium center.

Experimental Section

The following is a representative example of the synthesis a Weinreb amide from the corresponding aryl bromides via Pd-catalyzed carbonylation under atmospheric pressure CO. A complete description of all experimental details, including procedures for the preparation of benzamides and methyl esters, can be found in the Supporting Information. Note: carbon monoxide is a highly toxic gas and should only be used only in a well-ventilated fume hood and with proper leak detection equipment.

4-Cyano-3-fluoro-*N*-methoxy-*N*-methyl-benzamide (Table 2, entry 2)

An oven-dried culture tube (18 × 150 mm) equipped with a Teflon® coated magnetic stir bar was sealed with a 14/20 rubber septum (inverted), evacuated, backfilled with nitrogen and cooled under nitrogen. Pd(OAc)2 (2 mol %, 0.02 mmol, 0.02 equiv., 4.5 mg), Xantphos (2 mol %, 0.02 mmol, 0.02 equiv., 11.6 mg), *N, O*-dimethylhydroxylamine hydrochloride (1.5 mmol,

1.5 equiv., 146 mg), and Na_2CO_3 (3 mmol, 3 equiv., 318 mg) were added by briefly removing the rubber septum. The rubber septum then was secured with several wrappings of electrical tape. 4-bromo-2-fluorobenzonitrile (1 mmol, 0.200 g) and toluene (2 mL) were added dropwise via syringe. The reaction then was purged for ~ 30 seconds with $CO_{(g)}$; following the gas purge a balloon was connected to the reaction using a short length of rubber tubing (~ 1 in.), a needle adapter and a 20 G needle. This balloon was then inflated with $CO_{(g)}$, and the reaction tube was submerged in a 80 °C preheated oil bath. The reaction mixture was heated at 80 °C with vigorous stirring until the aryl halide had been completely consumed as judged by GC analysis (18 h). The reaction mixture was then allowed to cool to room temperature, diluted with ethyl acetate (~ 10 mL), filtered through a plug of celite (eluting with ethyl acetate) and concentrated under reduced pressure. The crude product mixture was purified by flash column chromatography on silica gel (20 % –50 % ethyl acetate in hexanes) to provide the title compound as a light yellow-orange solid (181 mg, 95 %), mp 43 – 44 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.71-7.66 (m, 1H), 7.60-7.52 (m, 2H), 3.54 (s, 3H), 3.38 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 166.38, 164.23, 160.79, 140.84, 140.74, 133.36, 124.70, 124.65, 116.64, 116.35, 113.42, 103.26, 103.06, 61.59, 33.17 (observed complexity due to C-F splitting; definitive assignments have not yet been made). ^{19}F NMR (282 MHz, $CDCl_3$) δ: −106.1. IR (neat, cm^{-1}): 3090, 2977, 2940, 2823, 2239, 1652, 1622, 1566, 1503, 1459, 1428, 1386, 1251, 1198, 1182, 1115, 990, 941, 887, 835, 750, 733, 714, 682, 668. Anal. Calcd for $C_{10}H_9FN_2O_2$: C, 57.69; H, 4.36. Found: C, 57.64; H, 4.37.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgment

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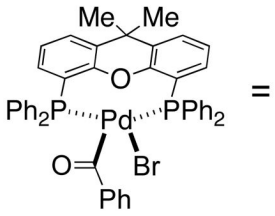
References

1. Collman, JP.; Hegedus, LS.; Norton, JR.; Finke, RG. Principles and Applications of Organotransition Metal Chemistry. Sausalito, CA: University Science Books; 1987. Chapters 3.6a and 12. (b) Beller M, Eckert M. Angew. Chem. Int. Ed 2000;39:1010. (c) Vizer SA, Yerzhanov KB, Al Quntar AAA, Dembitsky VM. Tetrahedron 2004;60:5499. (d) Hocking RK, Hambley. Organometallics 2007;26:2815.
2. Sen, A., editor. Catalytic Synthesis of Alkene-Carbon Monoxide Copolymers and Cooligomers. Dordrecht, The Netherlands: Springer; 2003.
3. Colquhoun, HM.; Thompson, DJ.; Twigg, MV. Carbonylation, Direct Synthesis of Carbonyl Compounds. New York: Plenum Press; 1991. (b) Beller M, Mägerlein W, Indolese AF, Fischer C. Synthesis 2001;7:1098. (b) Skoda-Földes R, Kollár L. Curr. Org. Chem 2002;6:1097.
4. (a) Schoenberg A, Bartoletti I, Heck RF. J. Org. Chem 1974;39:3318. (b) Schoenberg A, Heck RF. J. Org. Chem 1974;39:3327.
5. For representative examples describing the preparation of the following species via Pd-catalyed carbonylation see, a) enzamides: Martinelli JR, Clark TP, Watson DA, Munday RH, Buchwald SL. Angew. Chem. Int. Ed 2007;46:8460. (b) esters (from ArBr and HetArCl): Albaneze-Walker J, Bazaral C, Leavey T, Dormer PG, Murry JA. Org. Lett 2004;6:2097. [PubMed: 15200294] (c) esters (from ArOMs/Ts): Munday RH, Martinelli JR, Buchwald SL. J. Am. Chem. Soc 2008;130:2754. [PubMed: 18257577] (d) Weinreb amides: Martinelli JR, Freckmann DMM, Buchwald SL. Org. Lett 2006;8:4843. [PubMed: 17020317] (e) heterocyclic Weinreb amides: Deagostino A, Larini P, Occhiato EG, Pizzuto L, Prandi C, Venturello P. J. Org. Chem 2008;73:1941. [PubMed: 18220411]

(f) α-keto amides: Uozumi Y, Arii T, Watanabe T. J. Org. Chem 2001;66:5272. [PubMed: 11463289] (g) α-keto esters: Couve-Bonnaire S, Carpentier J-F, Mortreux A, Castanet Y. Adv. Synth. Catal 2001;343:289. (h) ketones: Goure WF, Wright ME, Davis PD, Labadie SS, Stille JK. J. Am. Chem. Soc 1984;106:6417. (i) aldehydes (from ArCl): Ben-David Y, Portnoy M, Milstein D. Chem. Commun 1989:1816. (j) aldehydes (from ArBr): Klaus S, Neumann H, Zapf A, Strübing D, Hübner S, Almena J, Riermeier T, Broβ P, Sarich M, Krahnert W-R, Rossen K, Beller M. Angew. Chem. Int. Ed 2006;45:154. (k) carboxylic acids: Pri-Bar I, Buchman OJ. J. Org. Chem 1988;53:624. (l) phenyl esters: Kubota Y, Hanaoka T-a, Takeuchi K, Sugi Y. Synlett 1994:515. (m) benzo-fused azoles: Perry RJ, Wilson BD, Miller RJ. J. Org. Chem 1992;57:2883. (n) coumarins: Kadnikov DV, Larock RC. J. Org. Chem 2003;68:9423. [PubMed: 14629168] (o) chromones: Kalinin VN, Shastakovsky MV, Ponomaryov AB. Tetrahedron Lett 1990;13:4073. (p) α,β-alkynyl ketones: Ahmed MSM, Mori A. Org. Lett 2003;5:3057. [PubMed: 12916980] (q) lactones: Cowell A, Stille JK. J. Am. Chem. Soc 1980;102:4193. (r)α-imino esters: Watanabe H, Hashizume Y, Uneyama K. Tetrahedron Lett 1992;33:4333. (s)β-keto esters: Raju PVK, Adapa SR. Indian J. of Chem., Sect. B 1992;31B:363. (t) naphthyridines: Addiati G, Arcadi A, Canevari V, Capezzuto L, Rossi E. J. Org. Chem 2005;70:6454. [PubMed: 16050709] (u) phthalimides: Perry RJ, Turner SR. J. Org. Chem 1991;56:6573. (v) pyrazoles and isoxaoles: Ahmed MSM, Kebayashi K, Mori A. Org. Lett 2005;7:4487. [PubMed: 16178565] (w) β-lactams: Dhawan R, Dghaym RD, St Cyr DJ, Arndtsen BA. Org. Lett 2006;8:3927. [PubMed: 16928040] (x) quinolones: Kalinin VN, Shostakovsky MV, Panomaryov AB. Tetrahedron Lett 1992;33:373.

6. Rahman O, Kihlberg T, Langstrom B. J. Org. Chem 2003;68:3558. [PubMed: 12713360]
7. Calo V, Giannoccaro P, Nacci A, Monopoli A. J. Organomet. Chem 2002;645:152.
8. (a) Morimoto T, Kakiuchi K. Angew. Chem. Int. Ed 2004;43:5589. (b) Wan Y, Alterman M, Larhed M, Hallberg A. J. Org. Chem 2002;67:6232. [PubMed: 12182668] (c) Wu X, Ronn R, Gossas T, Larhed M. J. Org. Chem 2005;70:3094. [PubMed: 15822969]
9. (a) Hidai M, Kokura K, Uchida Y. J. Organomet. Chem 1973;52:431. (b) Stromnova TA, Moiseev II. Russ. Chem. Rev 1998;67:485.
10. Kranenburg M, van der Burgt YE, Kamer PCJ, van Leeuwen PWNM. Organometallics 1995;14:3081.
11. (a) Guari Y, van Es DS, Reek JNH, Kamer PCJ, van Leeuwen PWNM. Tetrahedron Lett 1999;40:3789. (b) Wagaw S, Yang BH, Buchwald SL. J. Am. Chem. Soc 1999;121:10251.
12. Van der Veen LA, Keeven PH, Schoemaker GC, Reek JNH, Kamer PCJ, van Leeuwen PWNM, Lutz M, Spek AL. Organometallics 2000;19:872.
13. Leeuwen PWNM, Kamer PCJ, Reek JNH, Dierkes P. Chem. Rev 2000;100:2741. [PubMed: 11749304]
14. van Leeuwen PWNM, Zuideveld MA, Swennenhuis BHG, Freixa Z, Kamer PCJ, Goubitz K, Fraanje J, Lutz M, Spek AL. J. Am. Chem. Soc 2003;125:5523. [PubMed: 12720467]
15. Klingensmith LM, Strieter ER, Barder TE, Buchwald SL. Organometallics 2006;25:82.
16. (a) Kubota Y, Nakada S, Sugi Y. Synlett 1998:183. (b) Cai C, Rivera NR, Balsells J, Sidler RR, McWilliams JC, Schultz CS, Sun Y. Org. Lett 2006;8:5161. [PubMed: 17048868]
17. Watson DA, Fan X, Buchwald SL. manuscript submitted.
18. Amatore C, Carre E, Jutand A, M'Barki MA. Organometallics 1995;14:1818.
19. See Supporting Information.
20. Zuideveld MA, Swenneshuis BHG, Boele MDK, Guari Y, van Strijdonck GPF, Reek JNH, Kamer PCJ, Goubitz K, Fraanje J, Luta M, van Leeuwen PMNM. J. Chem. Soc., Dalton Trans 2002:2308.
21. (a) Yin J, Buchwald SL. J. Am. Chem. Soc 2002;124:6043. [PubMed: 12022838] (b) Fujita K, Yamashita M, Puschmann F, Alvarez-Falcon MM, Incarvito CD, Hartwig JF. J. Am. Chem. Soc 2006;128:9044. [PubMed: 16834372] (c) Grushin VV, Marshall WJ. J. Am. Chem. Soc 2006;128:12644. [PubMed: 17002347]
22. One exception in the recently prepared XantphosPd(CF_3)Ph, which has been shown to be cis configured in the solid-state. See reference21c.
23. (a) Milstein D. Acc. Chem. Res 1988;21:428. (b) Ozawa F, Kawasaki N, Okamoto H, Yamamoto T, Yamamoto A. Organometallics 1987;6:1640. (c) Lin Y-S, Yamamoto A. Organometallics 1998;17:3466.



=

1a

Selected Bond Lengths (Å)	
Pd(1)-C(40)	2.025(3)
O(2)-C(40)	1.202(4)
C(41)-C(40)	1.505(5)
Pd(1)-P(1)	2.3197(8)
Pd(1)-P(2)	2.5075(8)
Pd(1)-Br(1)	2.5101(4)

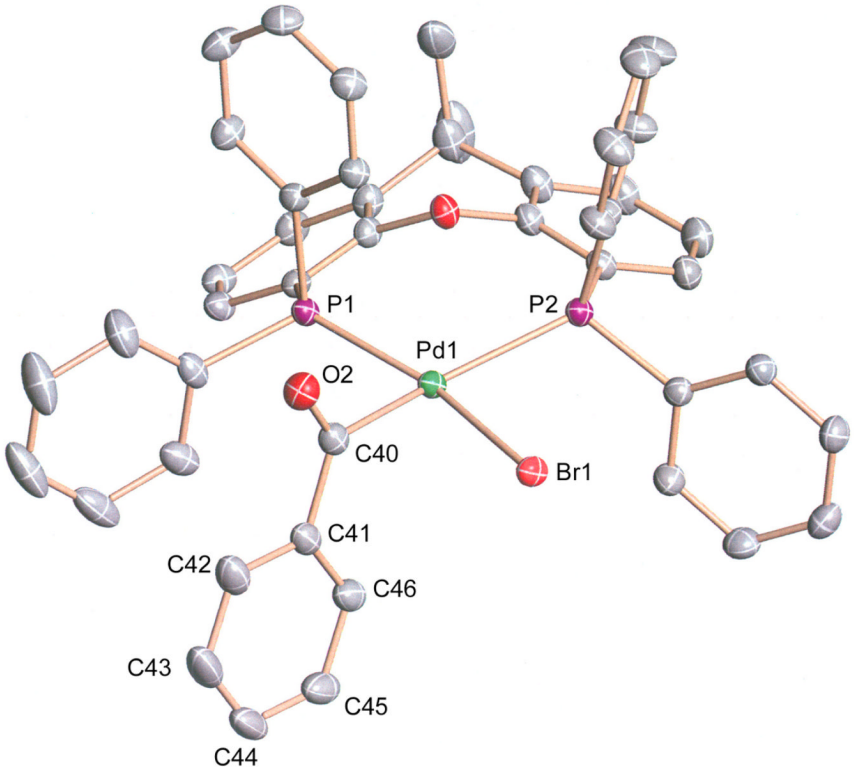
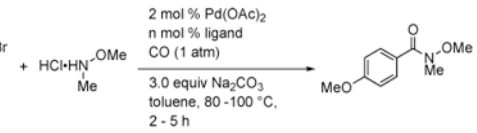


Figure 1.
X-Ray Crystal Structure and Selected Bond Lengths of (Xantphos)Pd(Br)COPh. Thermal ellipsoids at 30% probability and two THF molecules removed for clarity.



	temp (°C)	time	% conversion[b]	% yield[b]
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	< 1	0
	100	2 h	36	30
	100	5 h	90	87
	80	5 h	100	89[f]

ligand	temp (°C)	time	% conversion[b]	% yield[b]
dppf				
PPhos				

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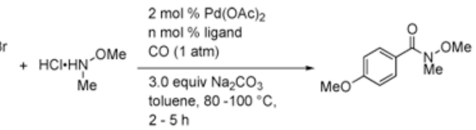

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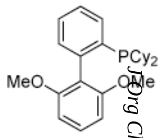
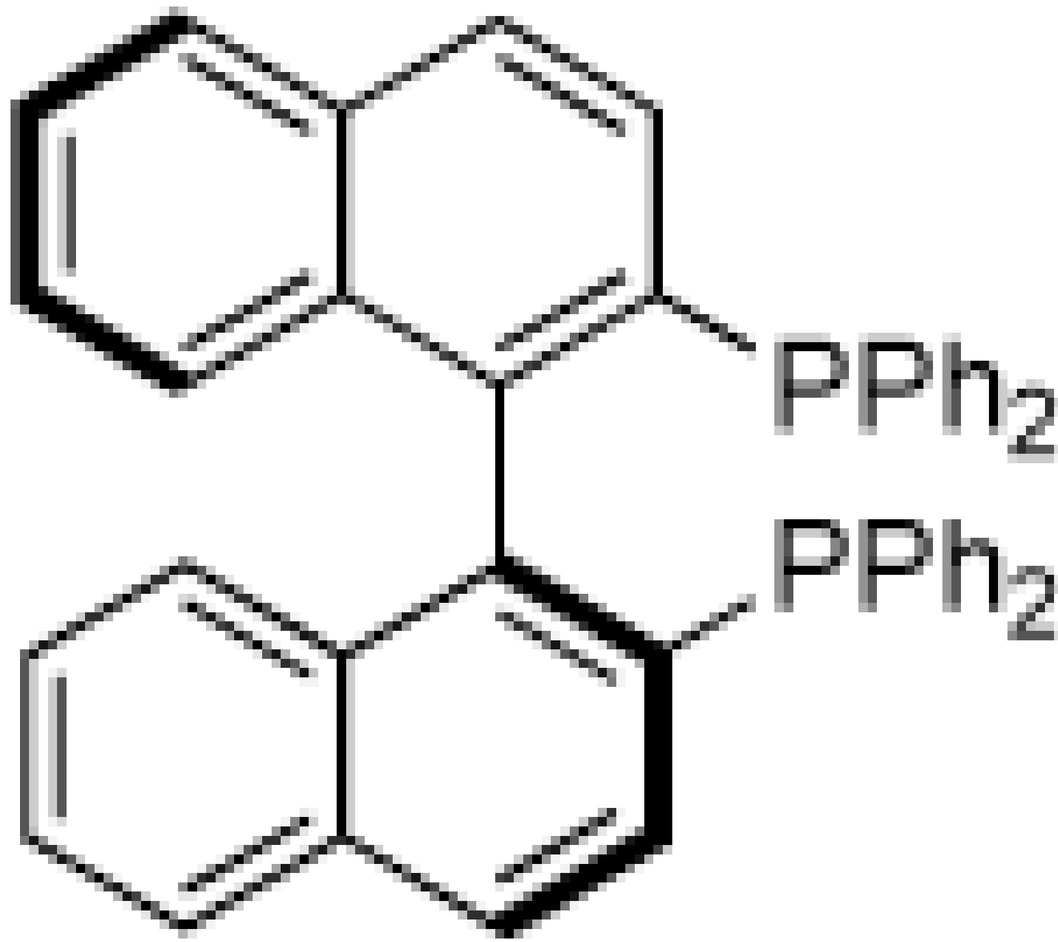
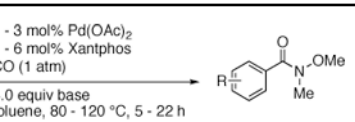
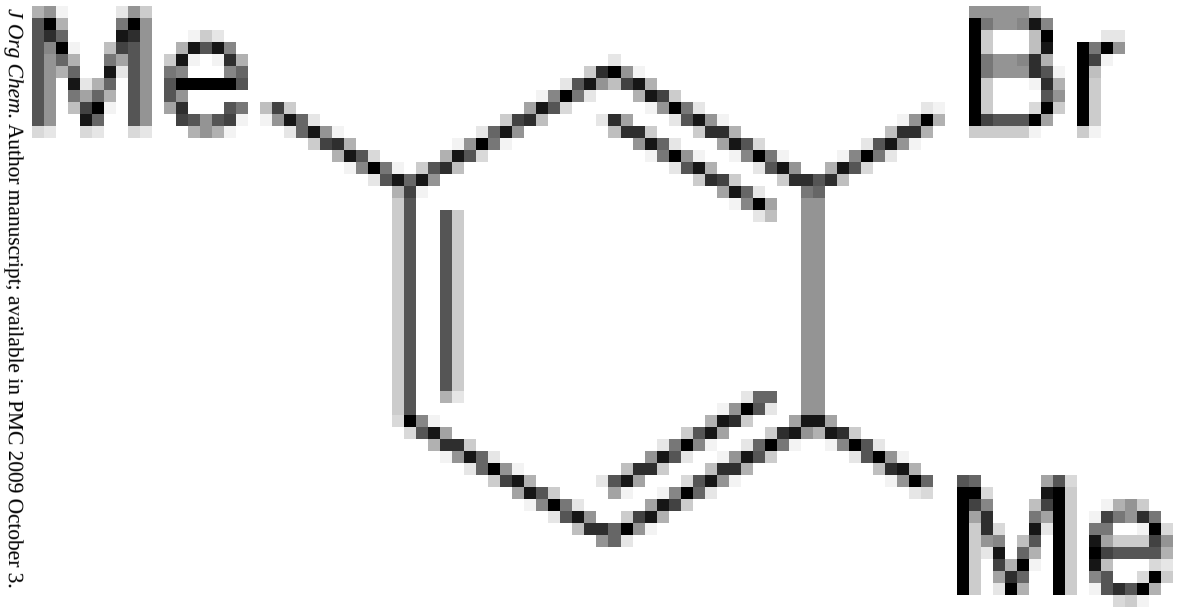
 SPhos				
 (S)-BINAP				

temp (°C)	time	% conversion[b]	% yield[b]



l[b]	entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
%	12		2.5% (2:1)	K_3PO_4	100°C	87%
%	13		2.5% (2:1)	K_3PO_4	100°C	97%

- 3 mol% $Pd(OAc)_2$
- 6 mol% Xantphos
O (1 atm)
0 equiv base
oluene, 80 - 120 °C, 5 - 22 h

entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
14		2.5% (2:1)	K_3PO_4	100°C	84%

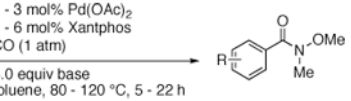
entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]

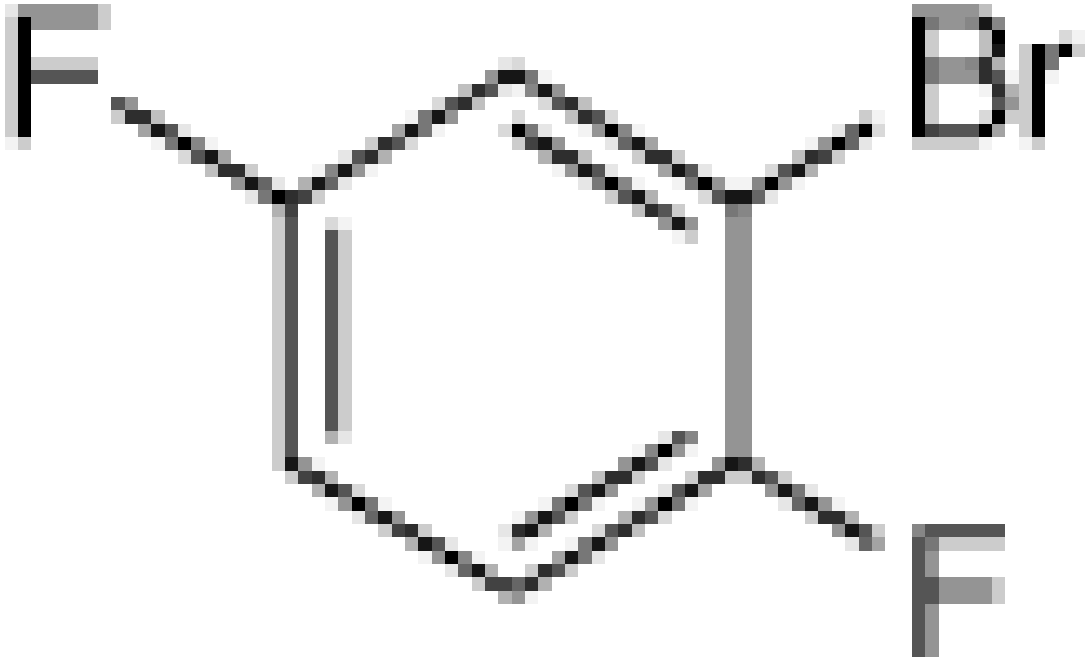
entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
15		3% (2:1)	K_3PO_4	100°C	80%

entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
16		3% (2:1)	K_3PO_4	100°C	81%

yield[b]	temp.	base	mol% Pd (L:Pd)	ArBr	entry
94%[c]	110°C	K_3PO_4	3% (2:1)		17
78%[c]	110°C	K_3PO_4	3% (2:1)		18

entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
19		3% (2:1)	K_3PO_4	120°C	90%[c]



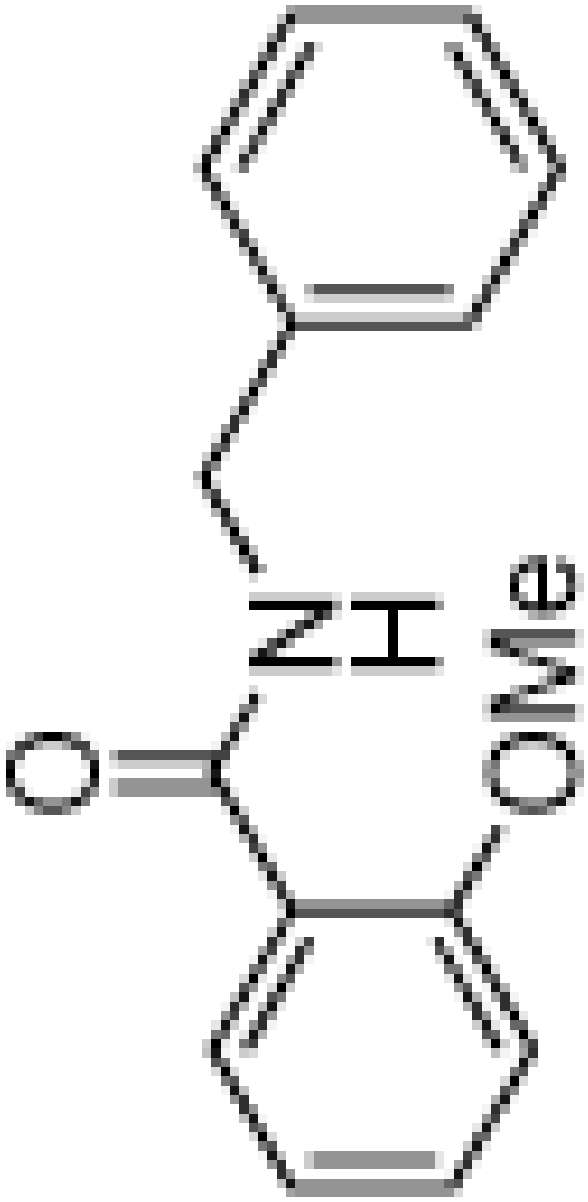
]b	entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
%	20		2.5% (2:1)	K_3PO_4	110°C	65%[c]

- 3 mol% $Pd(OAc)_2$
- 6 mol% Xantphos
O (1 atm)
0 equiv base
oluene, 80 - 120 °C, 5 - 22 h

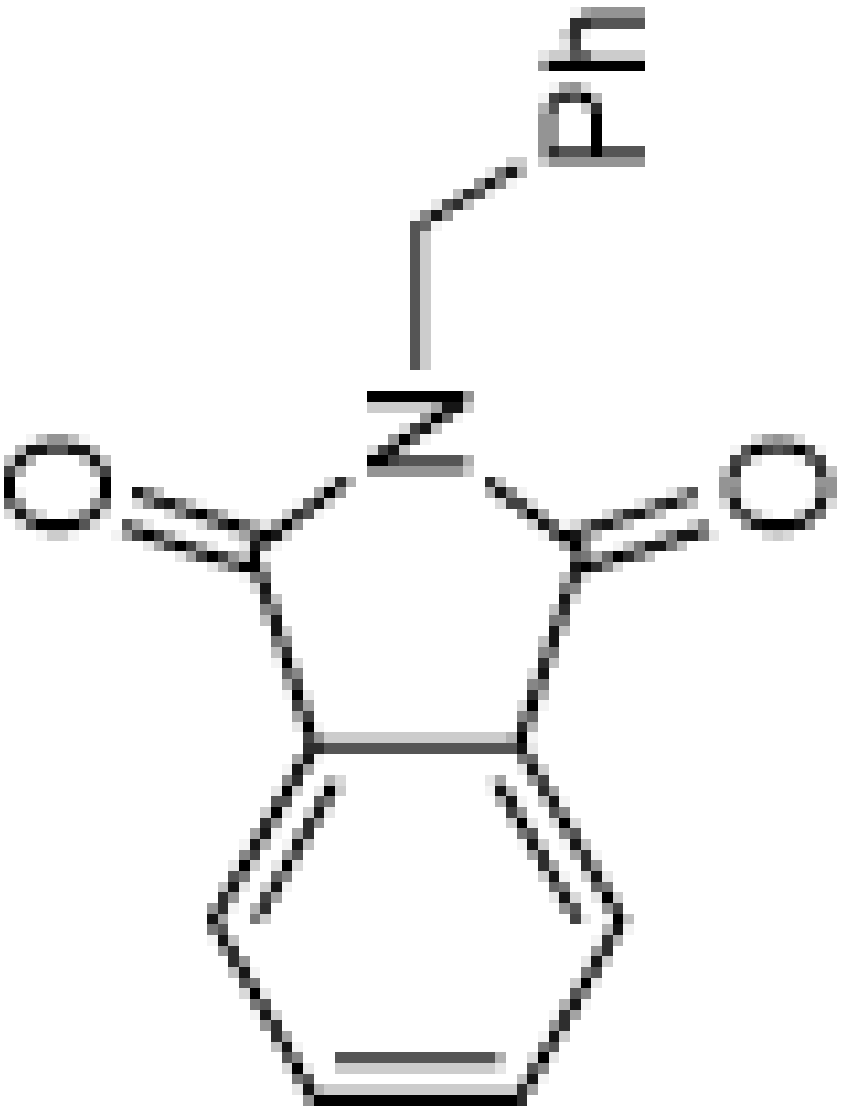
entry	ArBr	mol% Pd (L:Pd)	base	temp.	yield[b]
21		3% (2:1)	K_3PO_4	105°C	74%

	product	yield[b]
		86%[f]

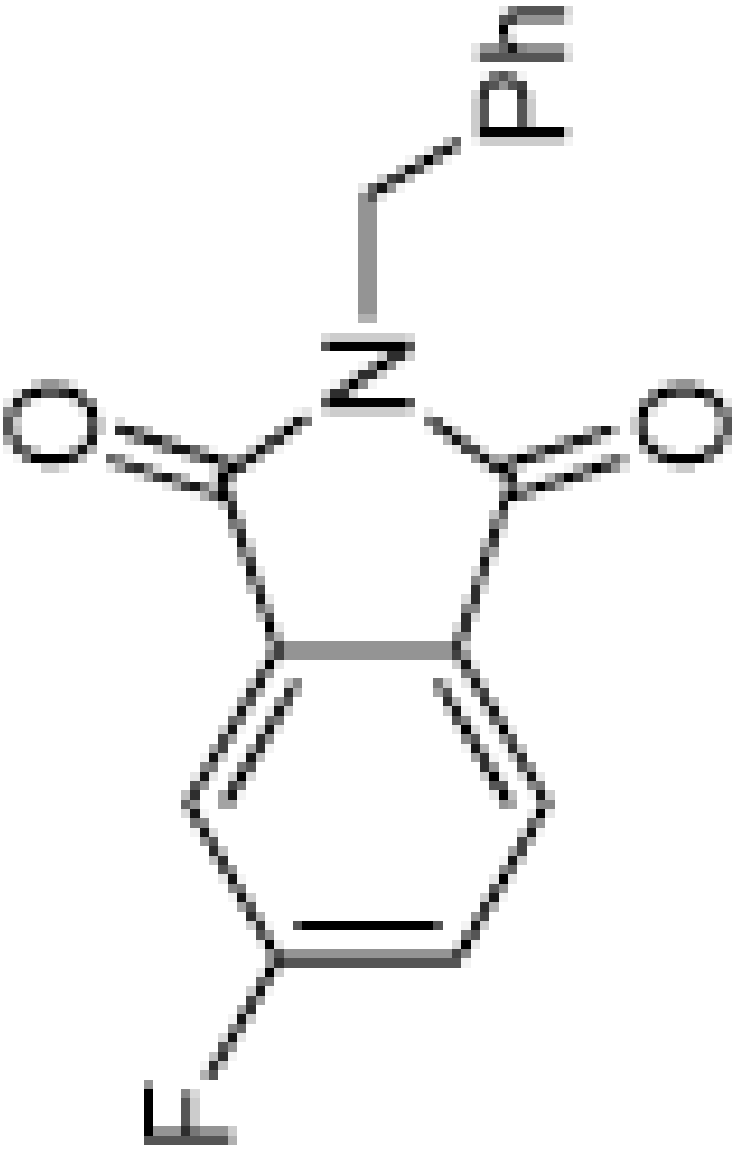
	product	yield[b]
		91%[f]

product	yield[b]
	94%[f]

product	yield[b]
	94%

product	yield[b]
	85%

product	yield[b]
	84%

product	yield[b]
	80%

product	yield[b]
	84%

	product	yield[b]
		78%[d]

product	yield[b]
	89%[d]

	3		92%
	4		89%
	5		91%
	6		90%

	3	4	5	6