

IASOC
19-23 September 2024, ISCHIA

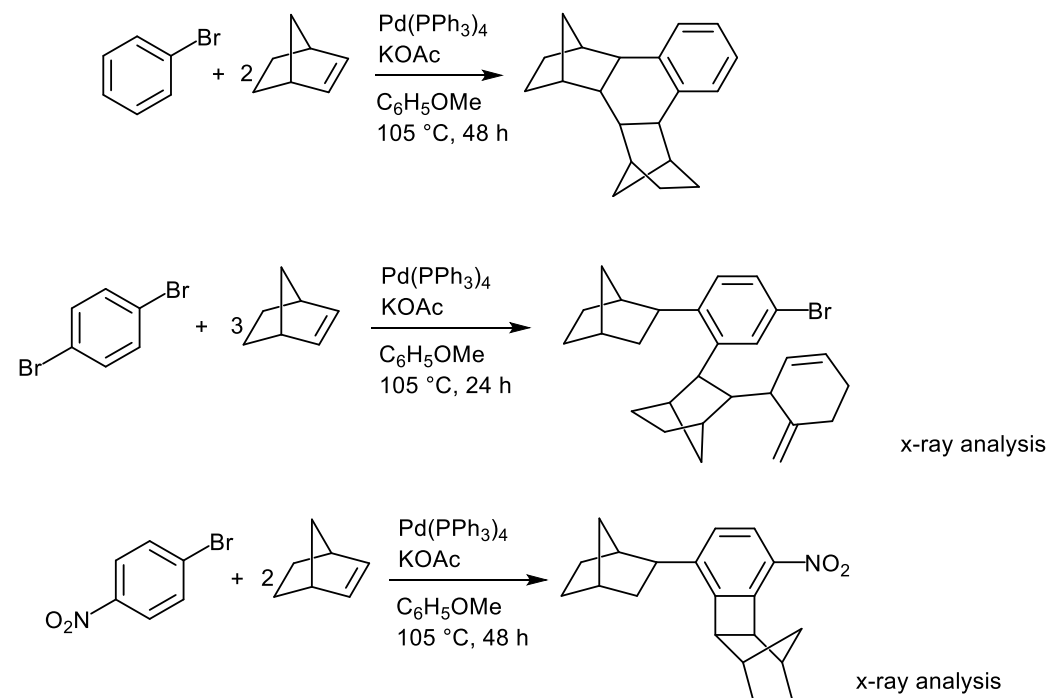
The lively chemistry of the Pd/norbornene duo

Marta Catellani

Università di Parma, 43121 Parma, Italy
marta.catellani@unipr.it

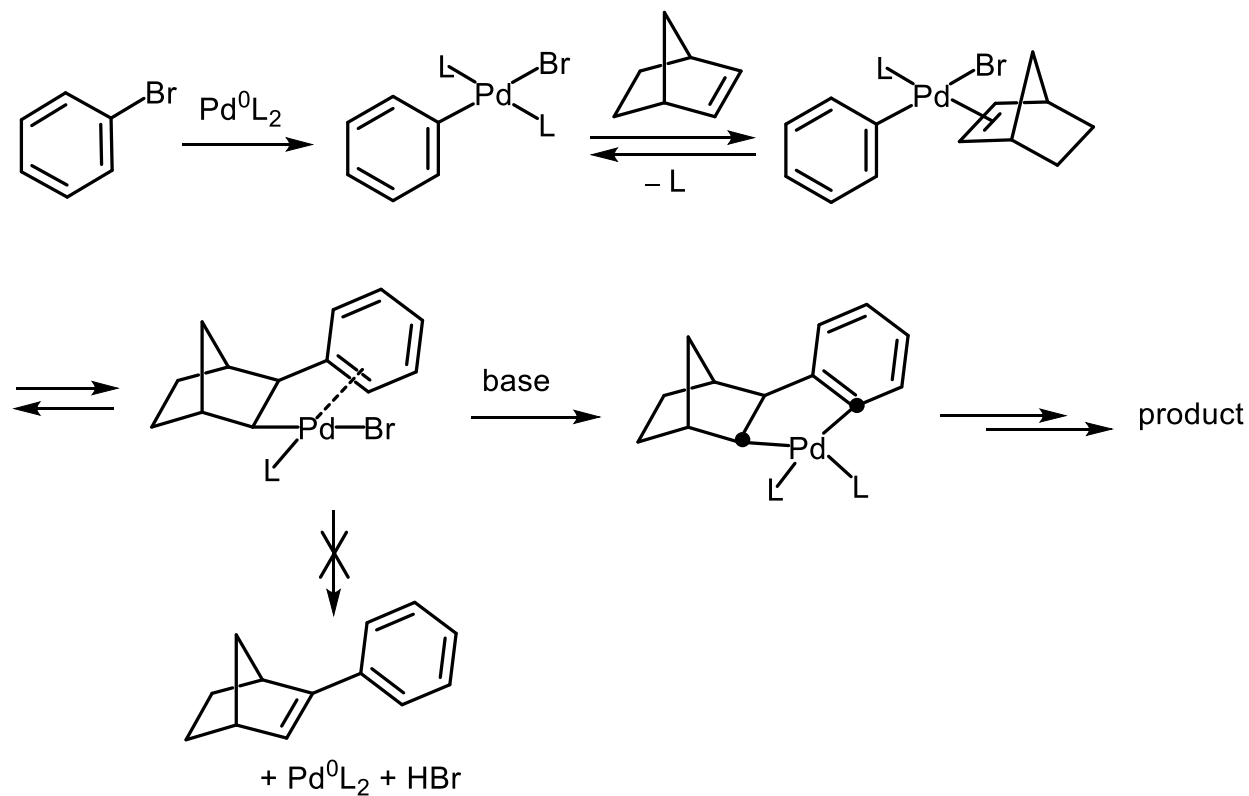
<https://www.youtube.com/watch?v=ws9Vs2acOXc>

Sequential reactions and aromatic C-H bond activation:
Bromobenzenes, norbornene and Pd(0)

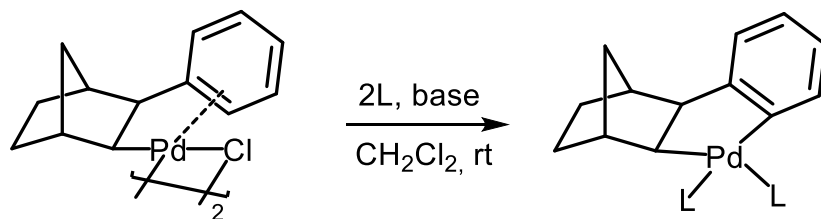


M. Catellani, G.P. Chiusoli JOMC 1982, 239, C35; G. Bocelli, M. Catellani, G.P. Chiusoli JOMC 1983, 247, C59; id. 1985, 279, 225
G. Bocelli, M. Catellani, G.P. Chiusoli, S. Larocca JOMC 1984, 265, C9

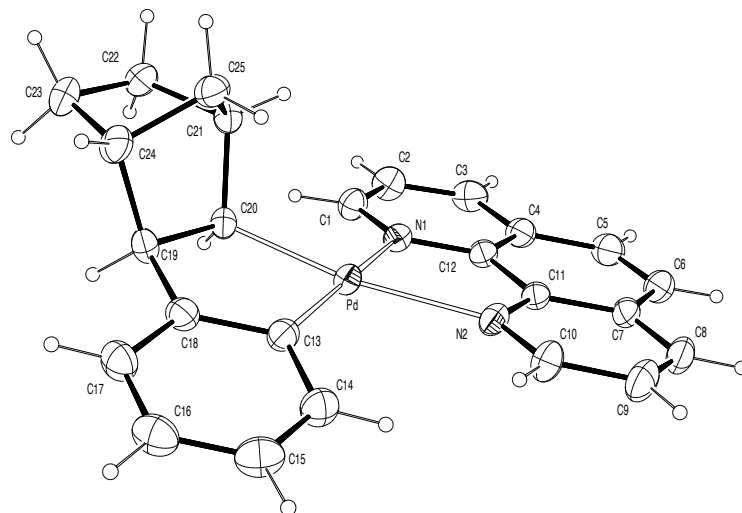
Bromobenzene, norbornene and Pd(0):
palladacycle intermediacy



Palladacycles



L = phenanthroline, bipyridyl, py, lutidine, methyl isonicotinate
base = PhOK

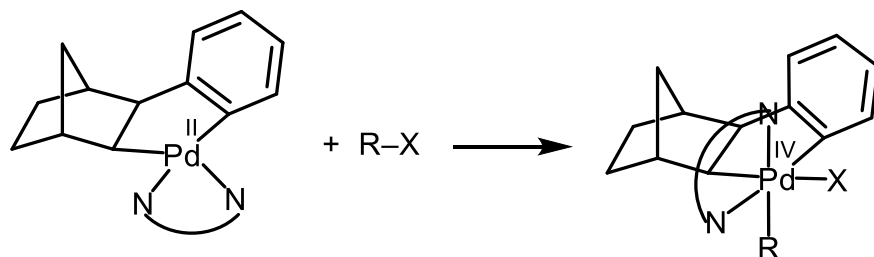


Selected Distances (Å)

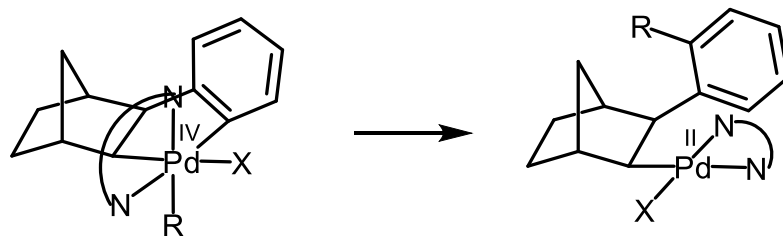
Pd-N1	2.145(3)
Pd-N2	2.216(3)
Pd-C13	2.016(5)
Pd-C20	2.029(4)


Reactivity of palladacycles through Pd(IV)

a) Oxidative addition to Pd(IV)

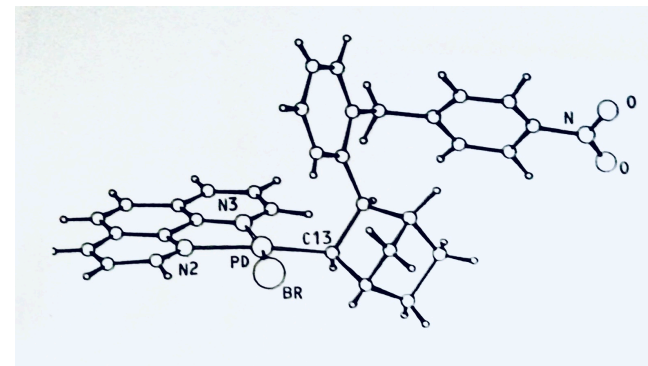


b) Reductive elimination to Pd(II)



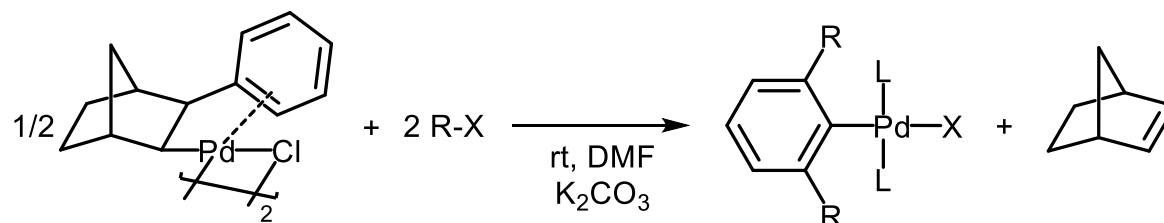
 = phenanthroline, bipyridyl

R = Me, allyl, C₆H₅CH₂, *p*-NO₂C₆H₄CH₂; X = Cl, Br, I



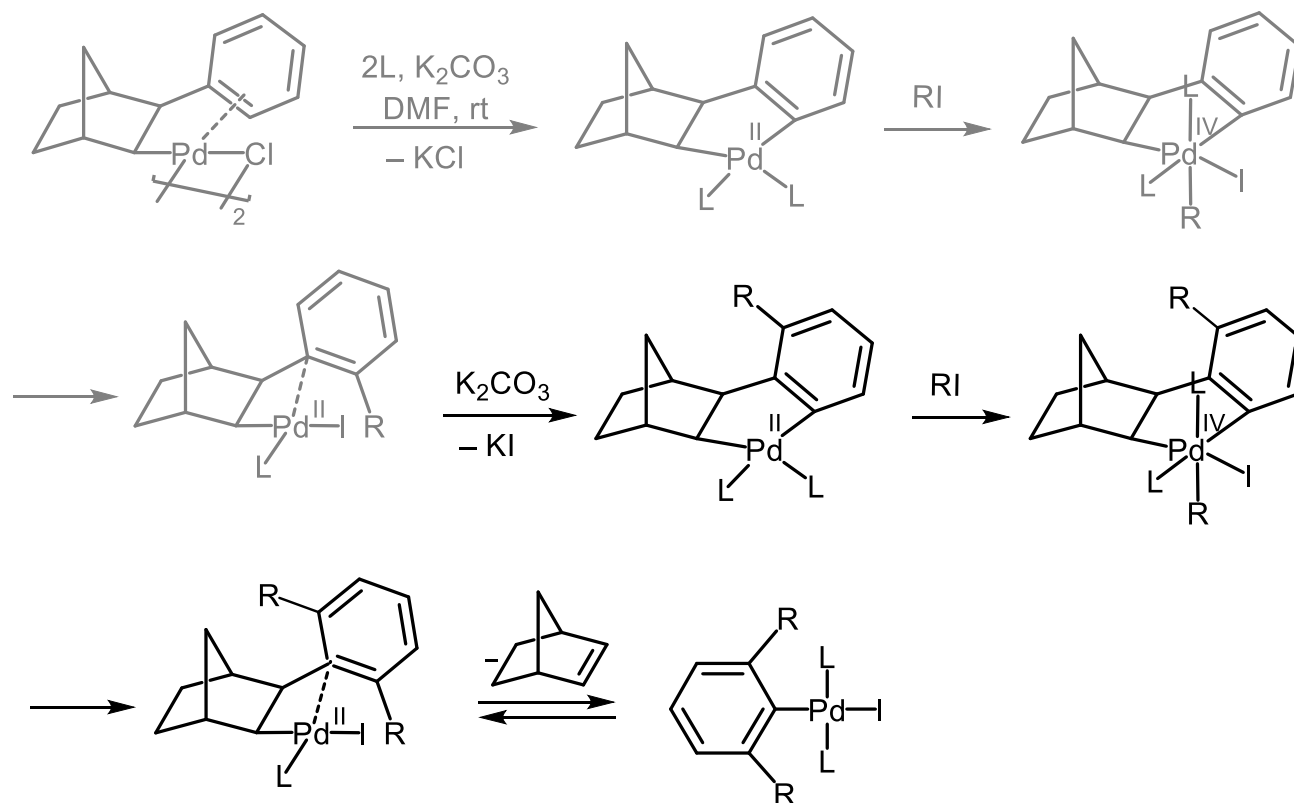
M. Catellani, B.E Mann, JOMC 1990, 390, 251; G. Bocelli, M. Catellani, S. Ghelli, JOMC 1993, 458, C12.

Palladacycles as intermediates for selective dialkylation of arenes and subsequent fragmentation

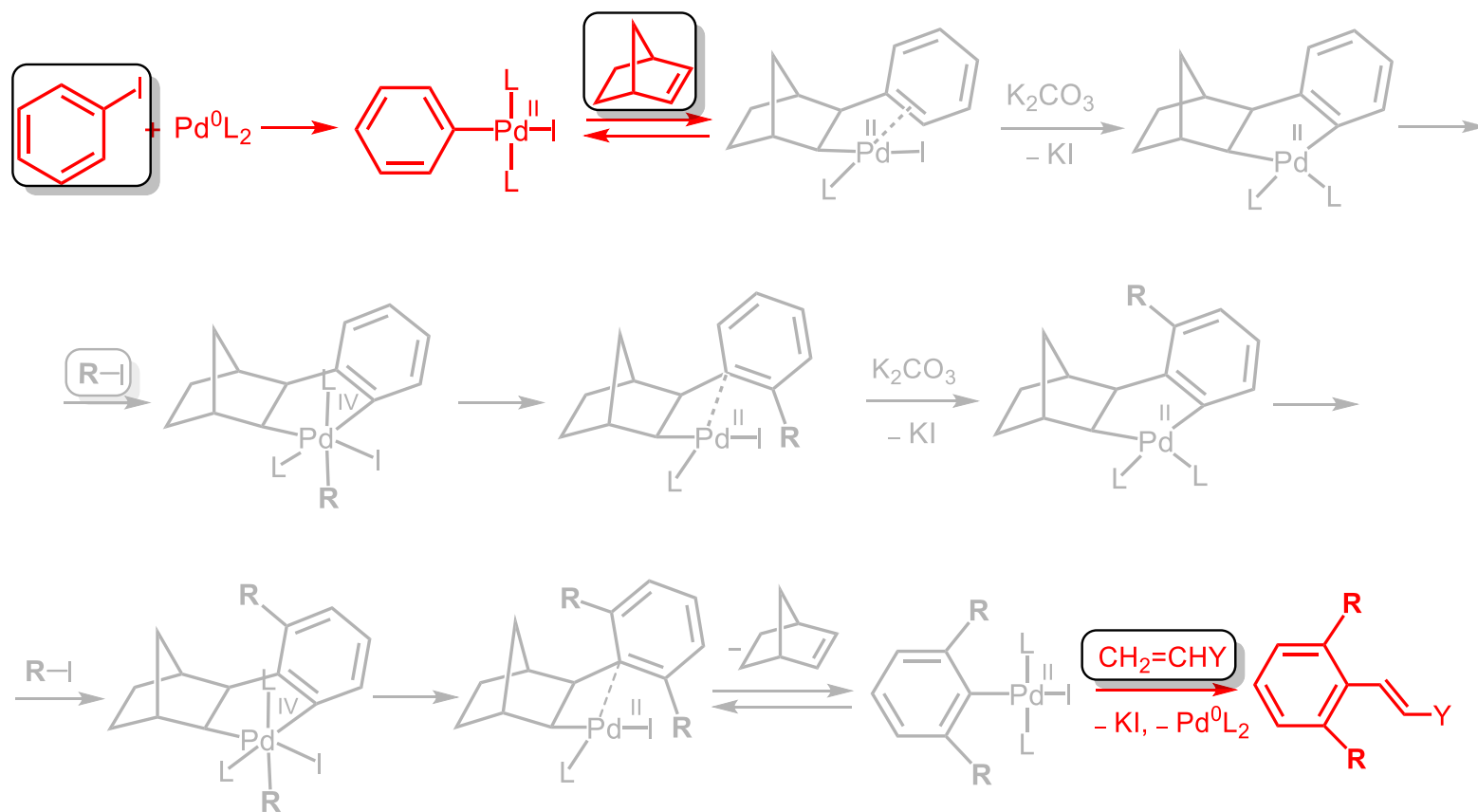


M. Catellani, M.C. Fagnola, ACIE, 1994, 33, 2421

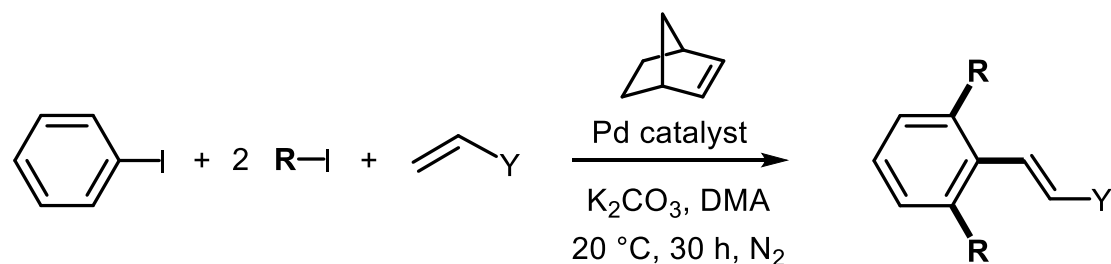
Palladacycles as intermediates for selective dialkylation of arenes and subsequent fragmentation



From stoichiometric to catalytic aromatic dialkylation

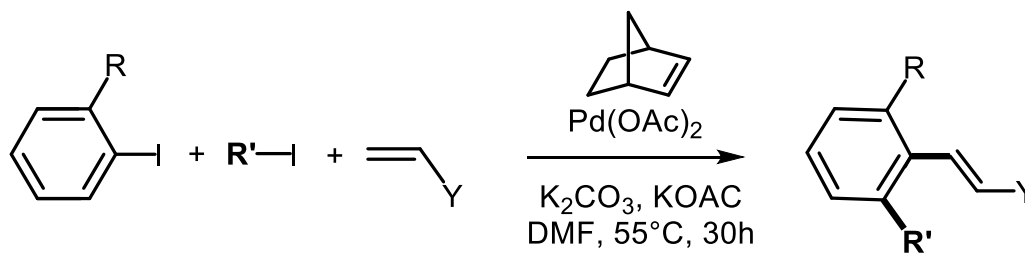
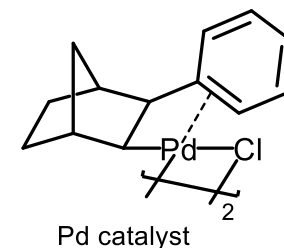


Selective aromatic dialkylation



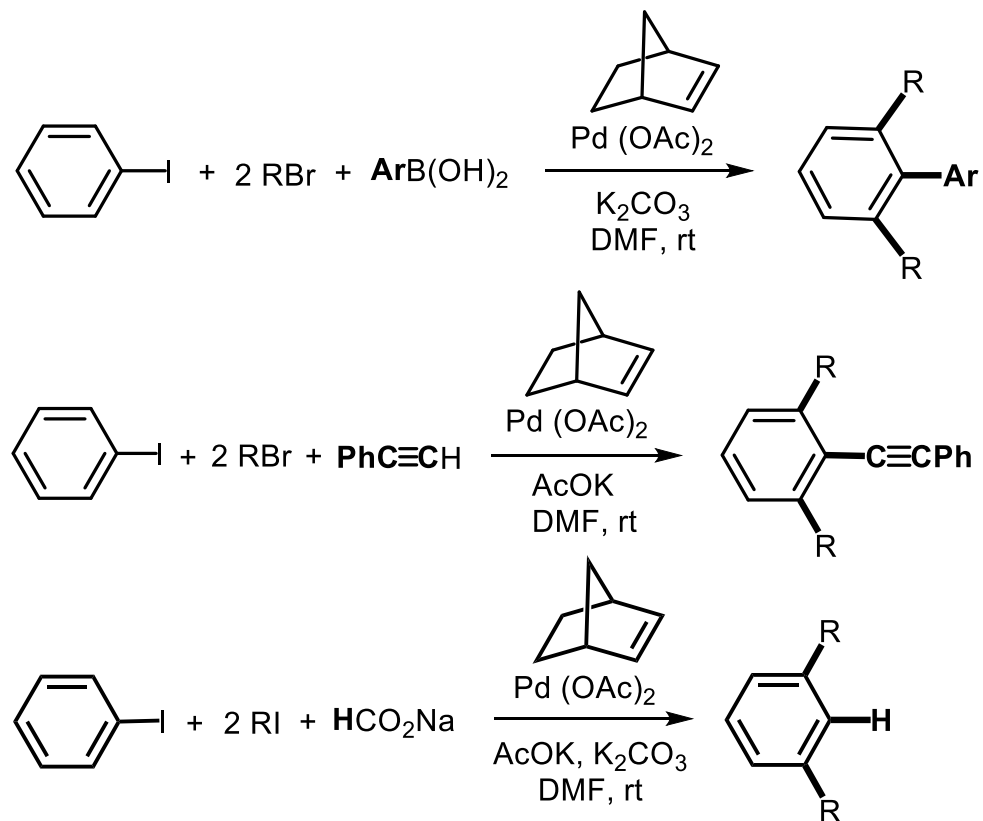
R = *n*-Bu, *n*-Oct, CF₃(CF₂)₂(CH₂)₂, PhCH₂CH₂
Y = CO₂Me, Ph, *n*-Hex

conversion: 31–100%
selectivity: 90–95%



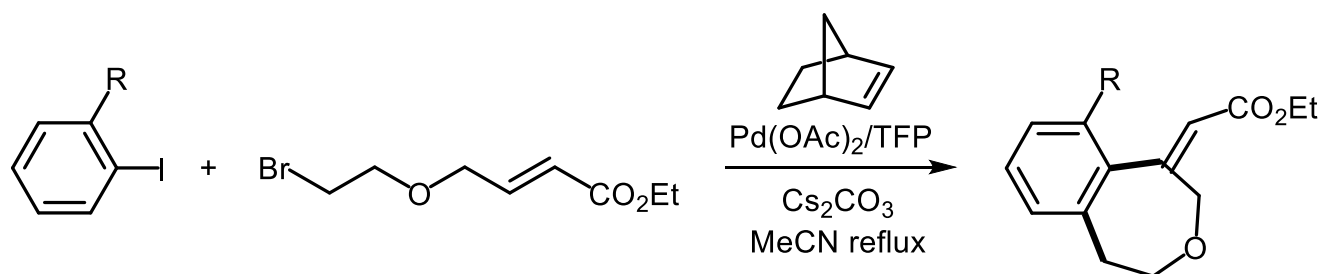
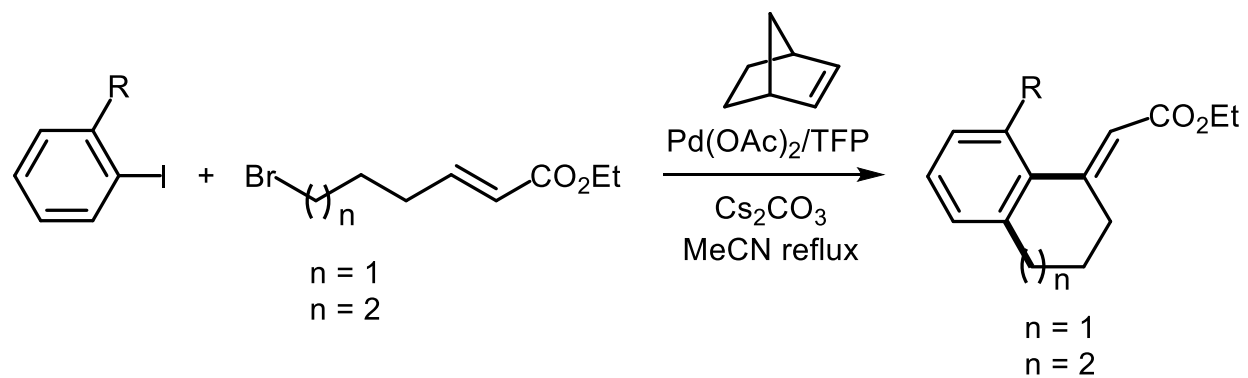
M. Catellani, F. Frignani, A. Rangoni, *ACIE* 1997, 36, 119
M. Catellani, F. Cugini, G. Bocelli, *Tetrahedron* 1999, 55, 6595

Selective Catalytic Aromatic Dialkylolation



M. Catellani, E. Motti, M. Minari, J. Chem. Soc. Chem. Comm. 2000, 157; E. Motti, M. Rossetti, G. Bocelli, M. Catellani JOMC 2004, 689, 3741; M. Catellani, Top. Organomet. Chem. 2005, 14, 21

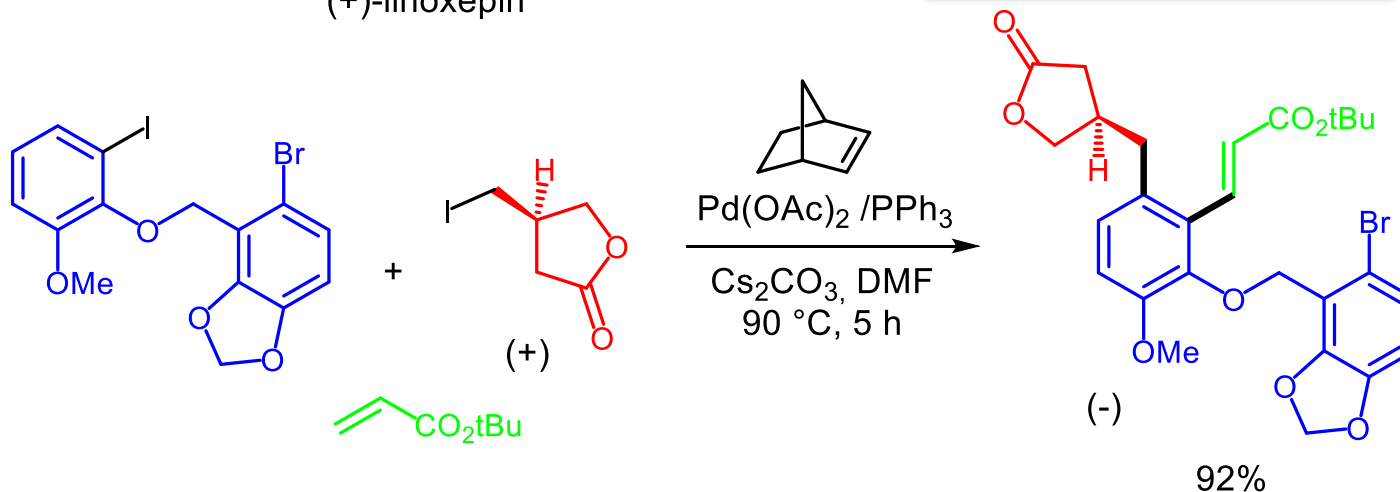
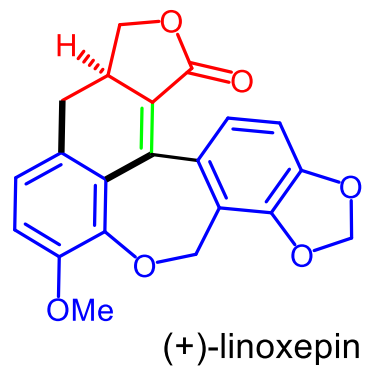
Synthesis of Cyclic Compounds



M. Lautens, S. Piguel, *ACIE* 2000, 39, 1045

M. Lautens, J.F. Paquin, S. Piguel, *J. Org. Chem.* 2002, 67, 3972

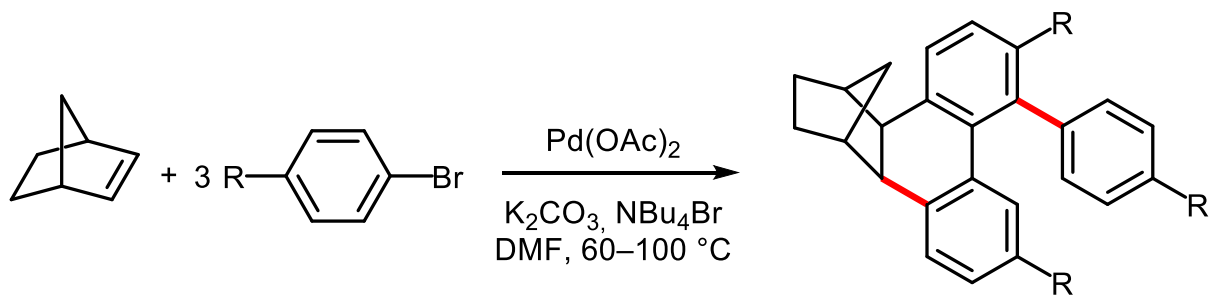
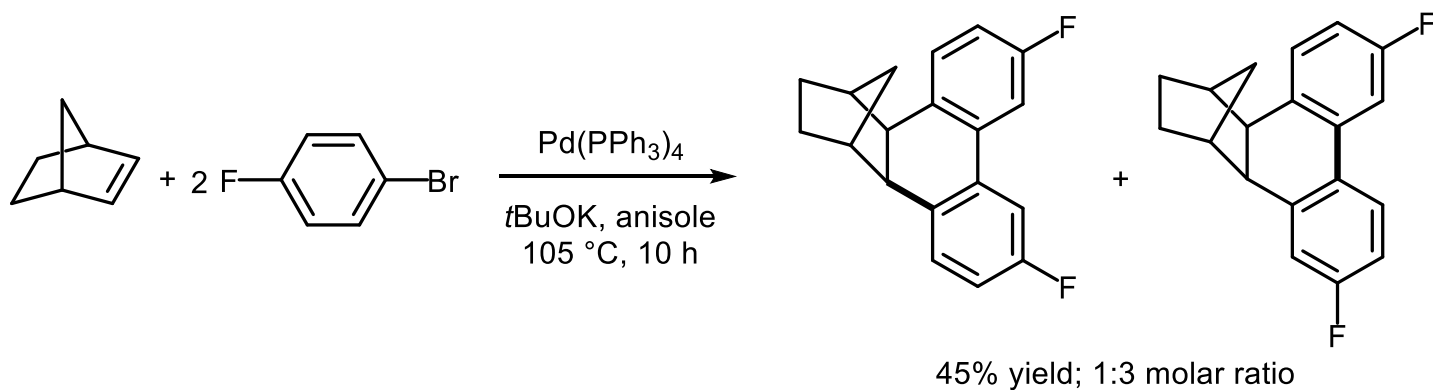
A key-intermediate in the total synthesis of (+)-Linoxepin



H. Weinstabl, M. Suhartono, Z. Qureshi, M. Lautens, *ACIE* 2013, 52, 5305

Z. Qureshi, H. Weinstabl, M. Suhartono, H. Liu, P. Thesmar, M. Lautens, *EJOC* 2014, 4053

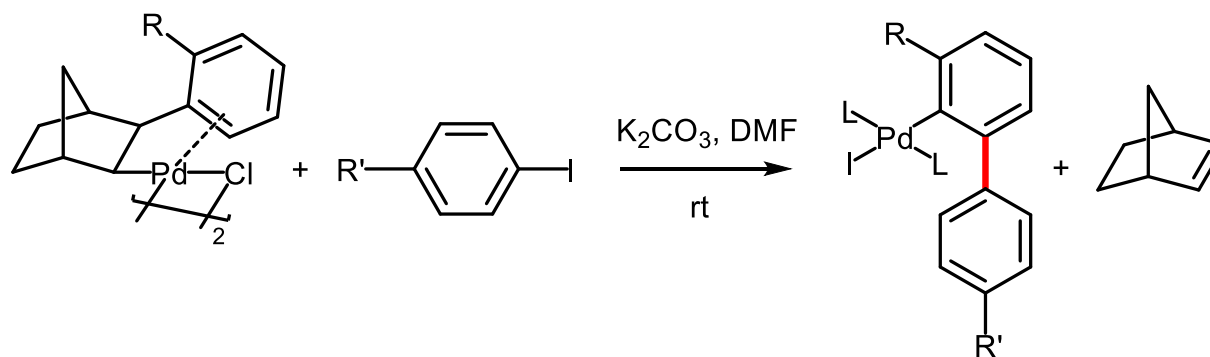
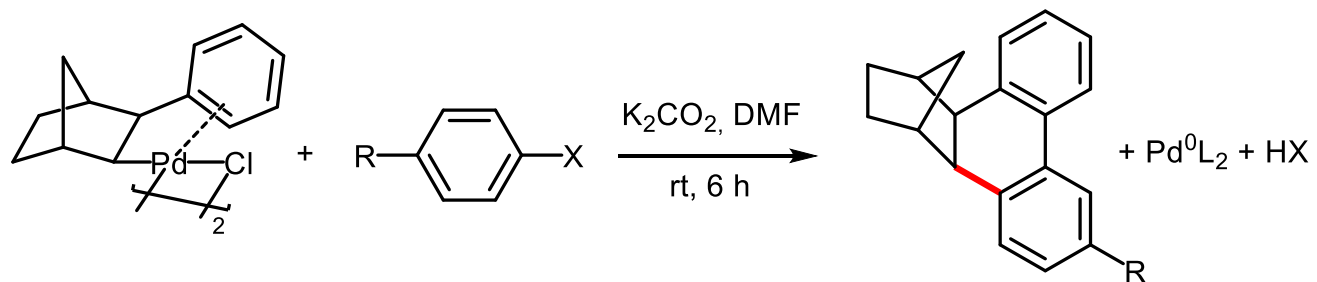
Aromatic Arylation: Catalytic Processes



M. Catellani, G.P. Chiusoli JOMC1985, 286, C13

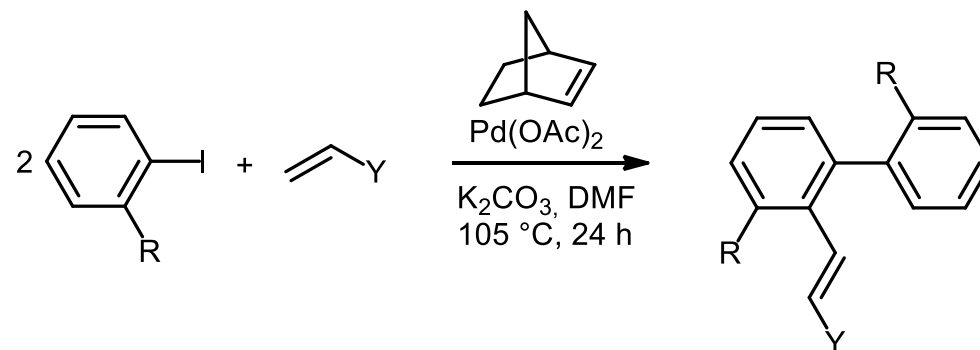
O. Reiser, M. Weber, A. de Meijere ACIE 1989, 28, 1037; K. Albrecht, O. Reiser, M. Weber, B. Knieriem, A. de Meijere, Tetrahedron 1994, 50, 383

Aromatic arylation: Stoichiometric Reactions

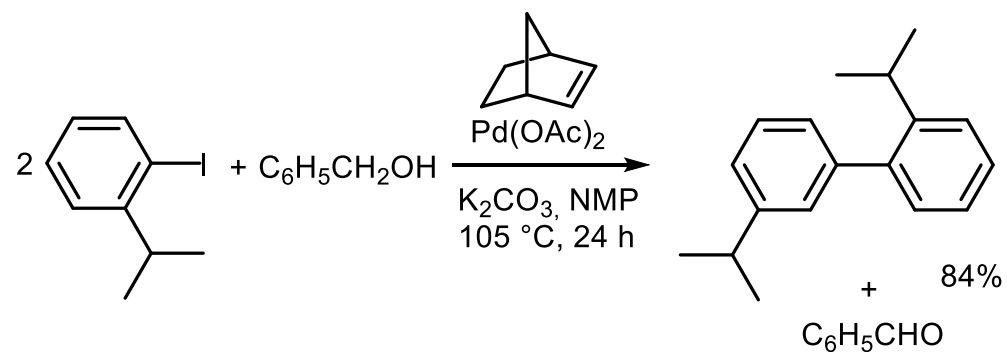


M. Catellani, E. Motti, *New J. Chem.* 1998, 22, 759

Synthesis of vinylbiaryls

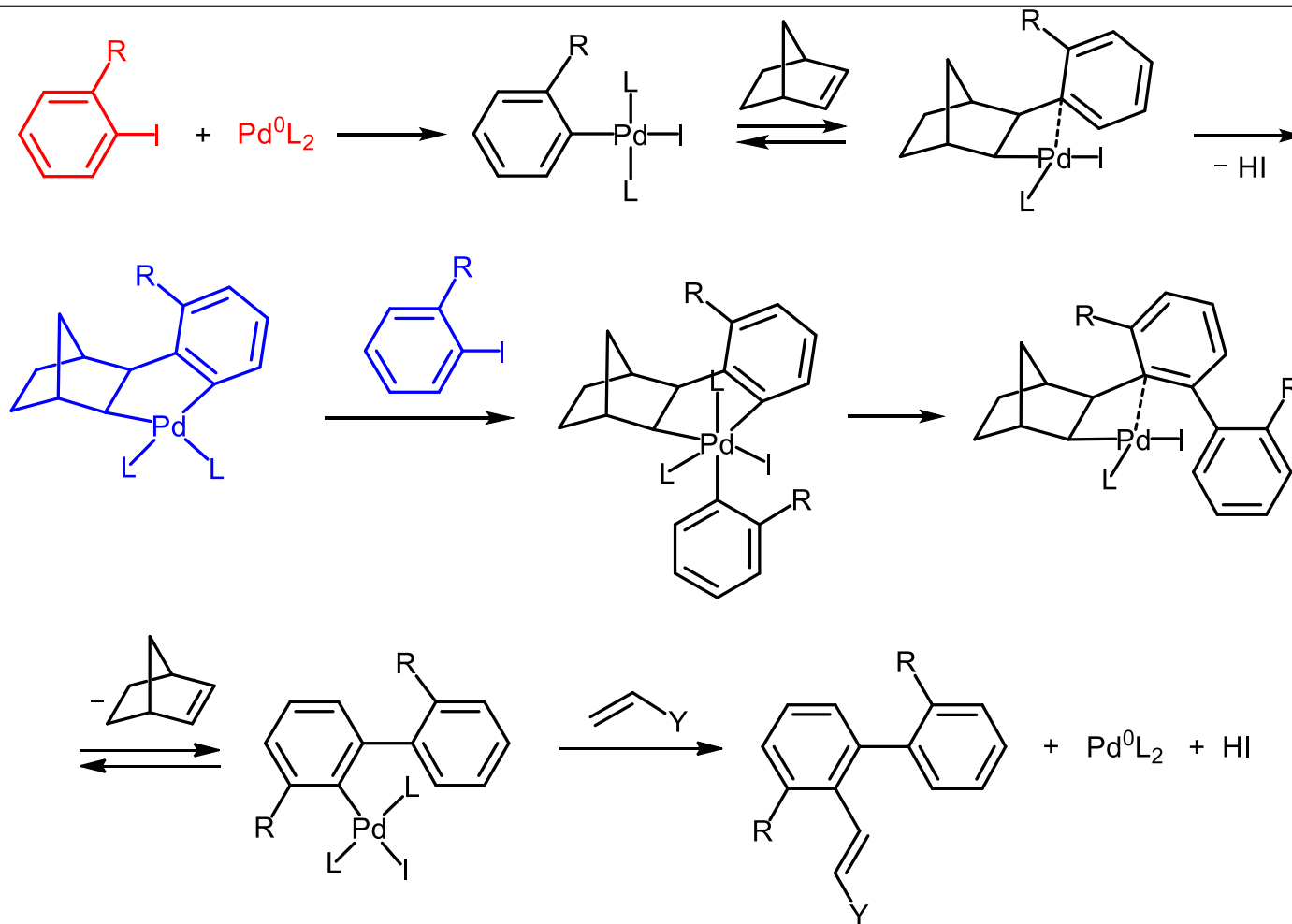


Synthesis of biaryls

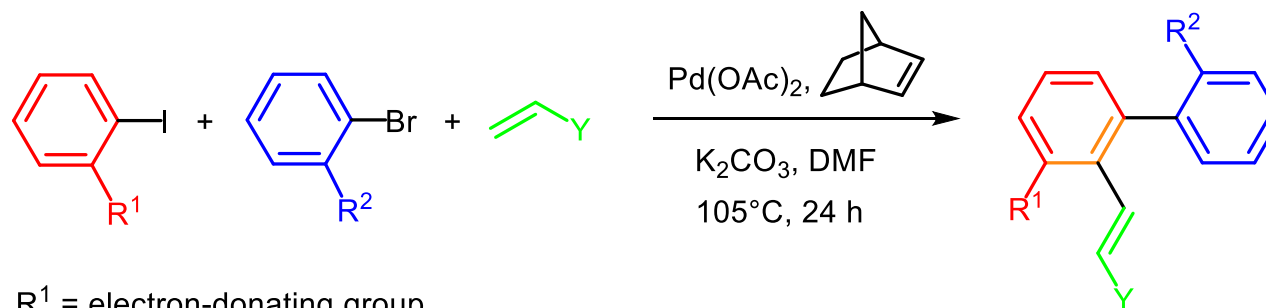


E. Motti, G. Ippomei, S. Deedda, M. Catellani, *Synthesis*, 2003, 2671; S. Deledda, E. Motti, M. Catellani, *Can. J. Chem.* 2005, 83, 741

Reaction Pathway



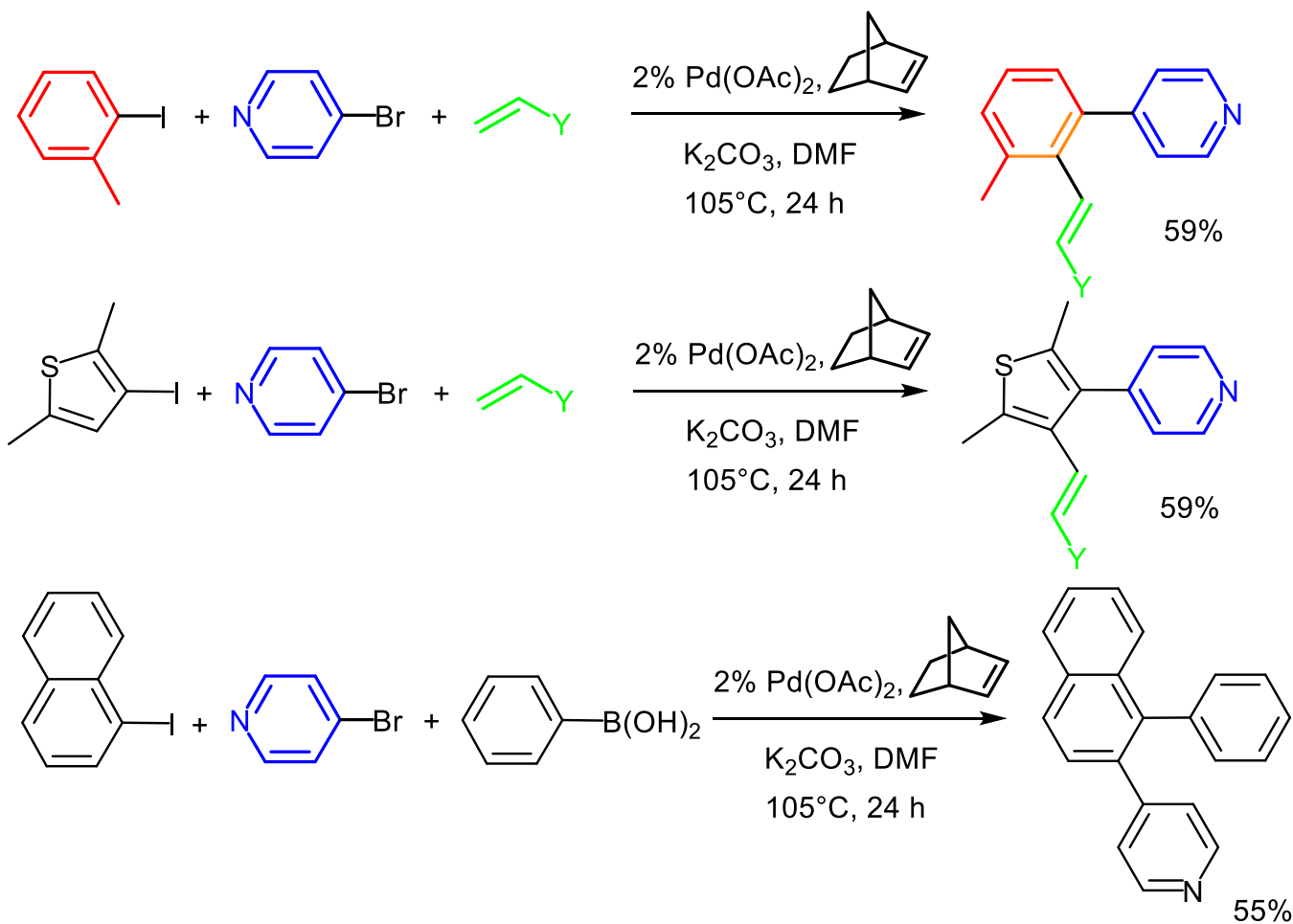
Synthesis of Vinyl Derivatives of Unsymmetrical Biaryls



R¹ = electron-donating group
R² = electron-withdrawing group
Y = CO₂Me, Ph, C₆H₁₃, O-*n*-Bu

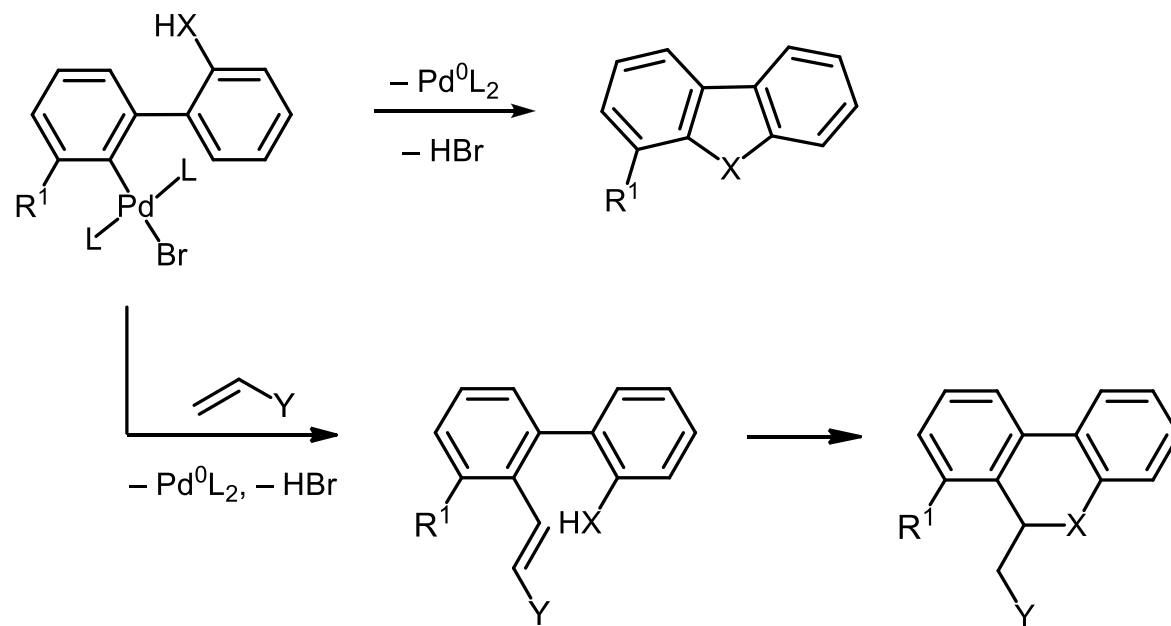
Names JACS, 2004, 126, 78

Heteroatom-containing coupling products

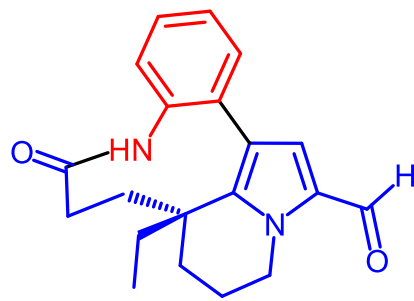


M. Catellani, E. Motti, N. della Ca' Acc. Chem. Res, 2008, 41, 1512

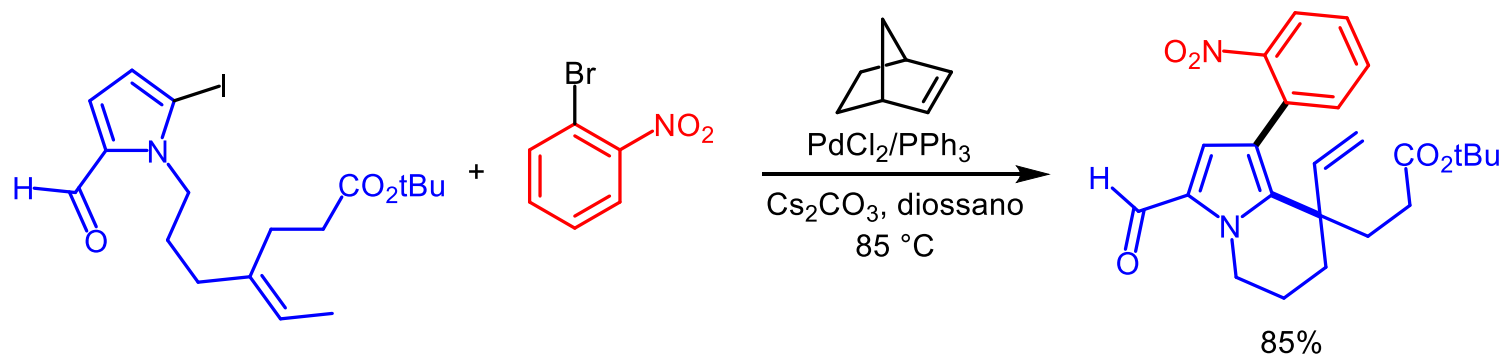
Condensed tricyclic compounds: *o*-substituted aryl bromides



A key-intermediate in the total synthesis of Rhazinal

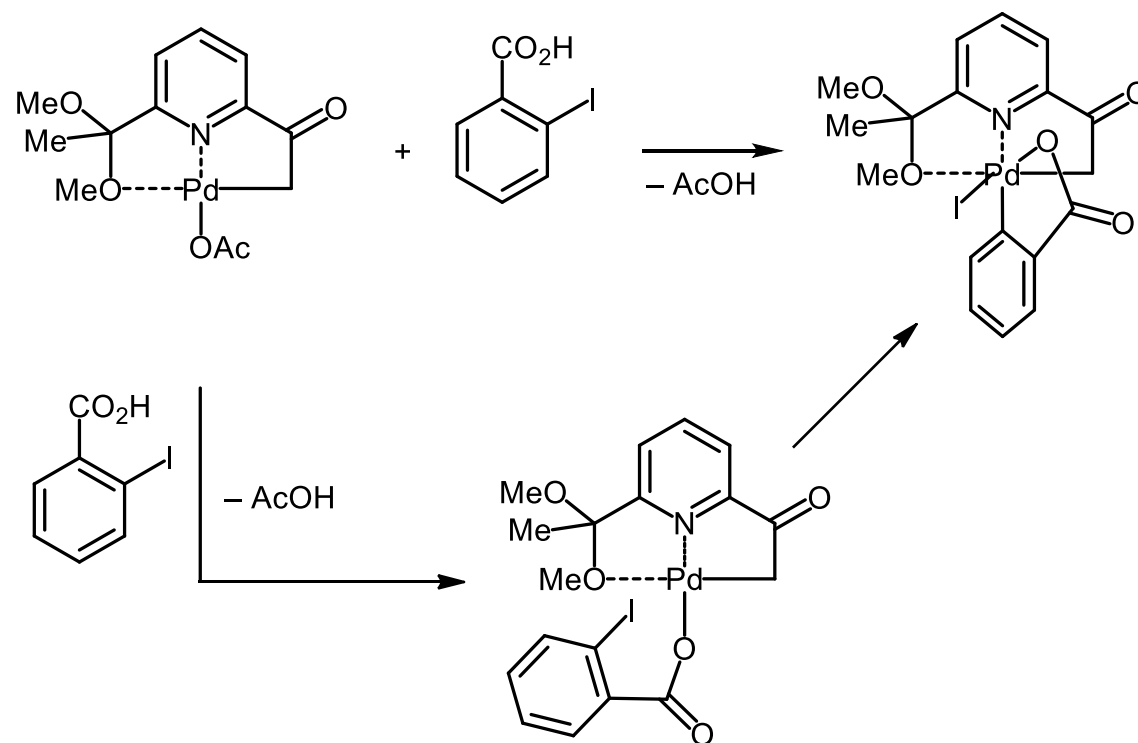


rhazinal



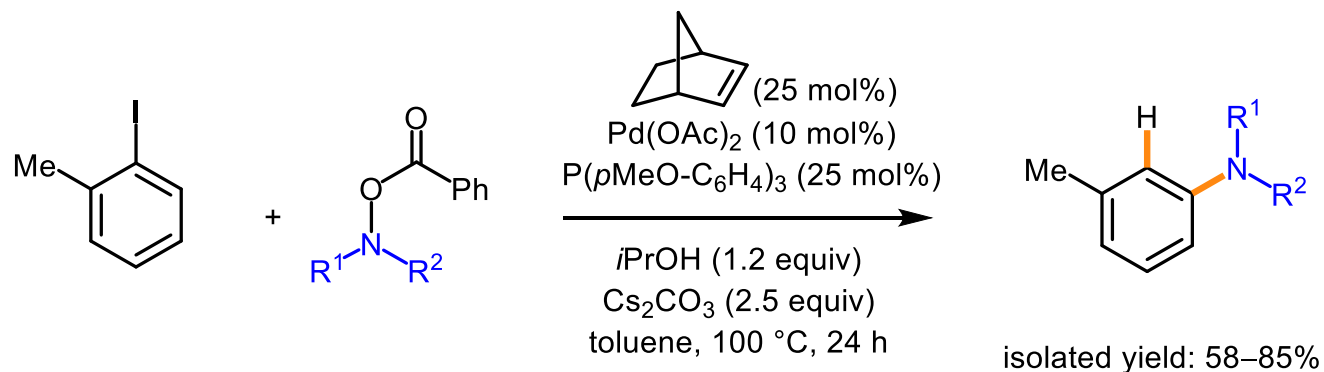
X. Sui, R. Zhu, G. Li, X. Ma, Z. Gu, JACS 2013, 135, 9318

Synthesis of a Pd(IV) complex by oxidative addition of an aryl halide to Pd(II)

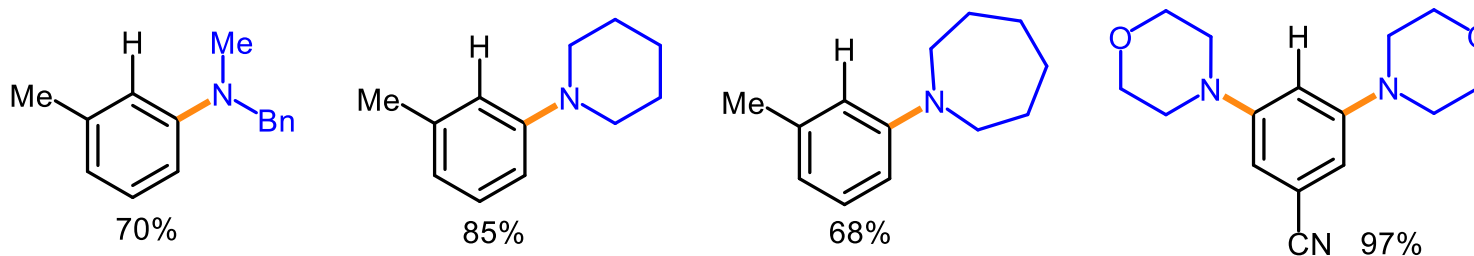


J. Vicente, A. Arcas, F. Juli-Hernández, D. Bautista, *ACIE*, 2011, 50, 6896

Pd/ Norbornene-catalyzed *ortho*-amination of aryl halides by *N*-benzoyloxoamines

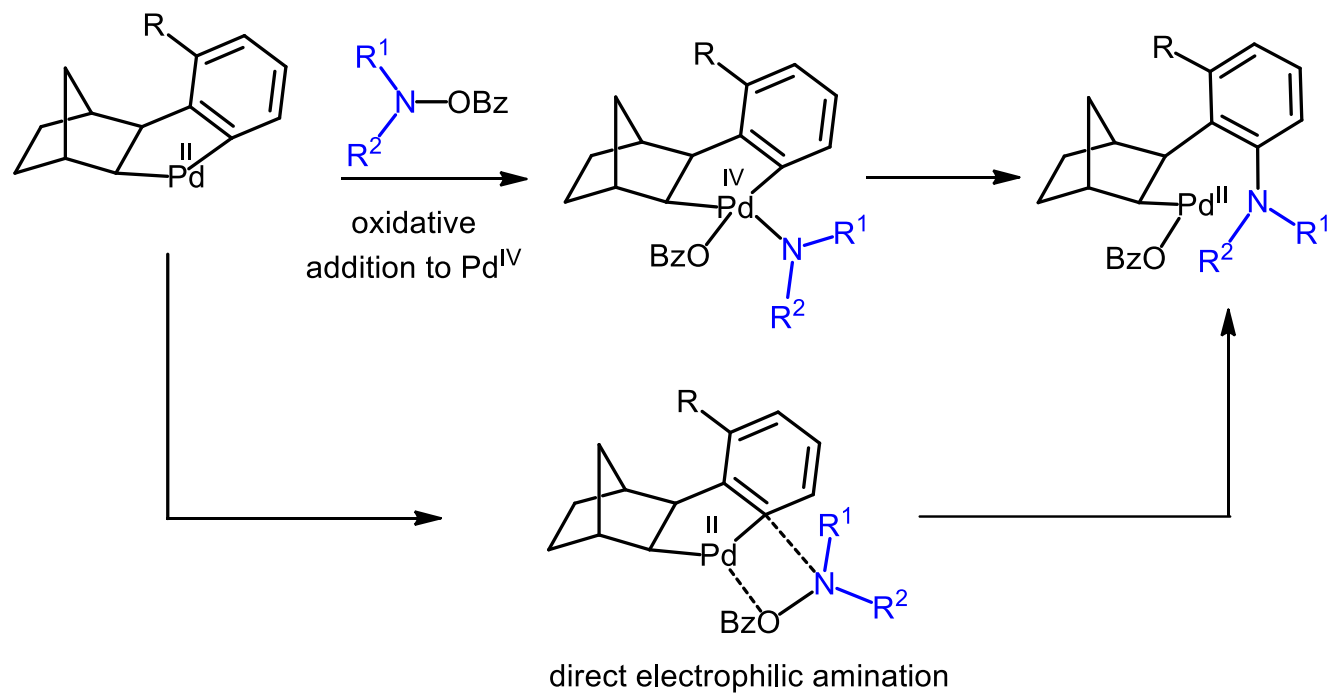


Selected examples



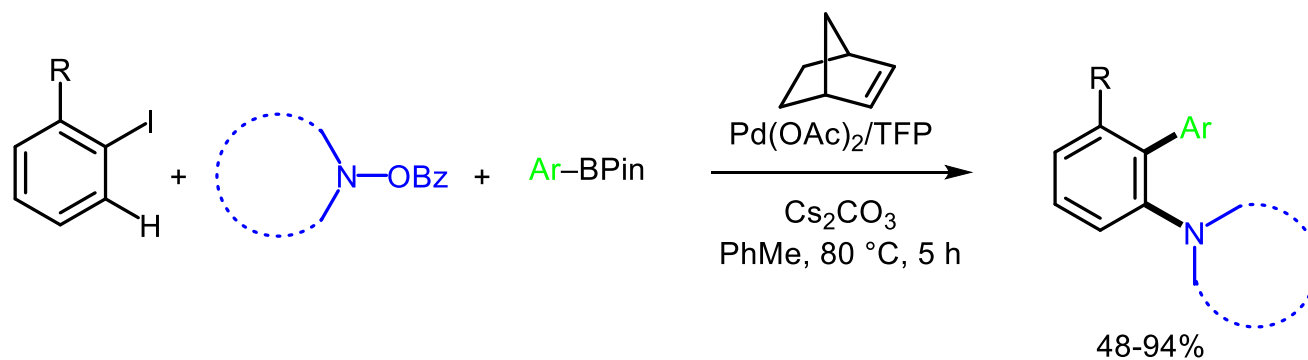
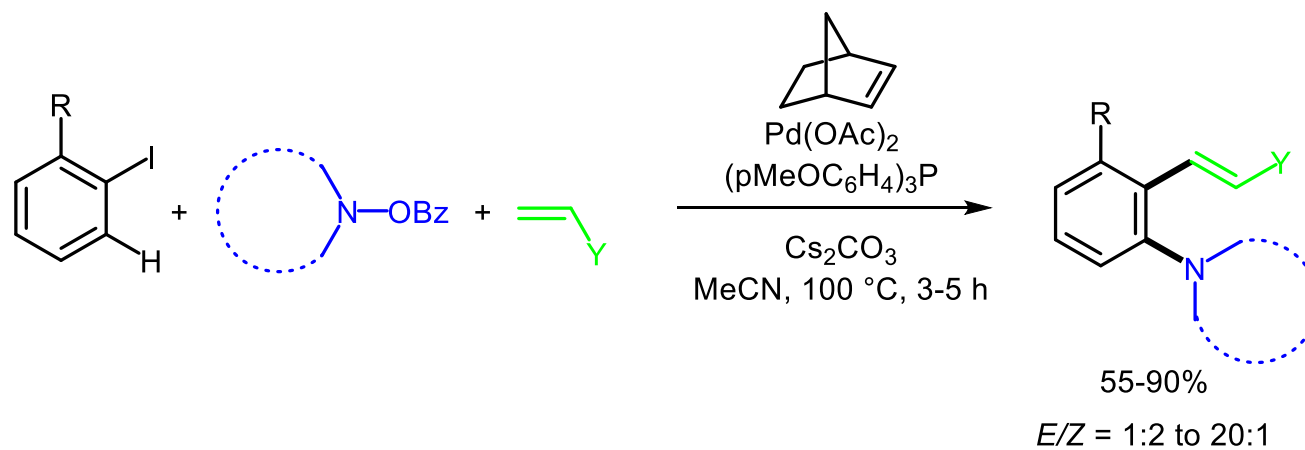
Z. Dong, G. Dong, JACS 2013, 135, 18350

Proposed Reaction Pathway



«...the first ortho C-N bond-forming transformations with an electrophilic amination reagent...»

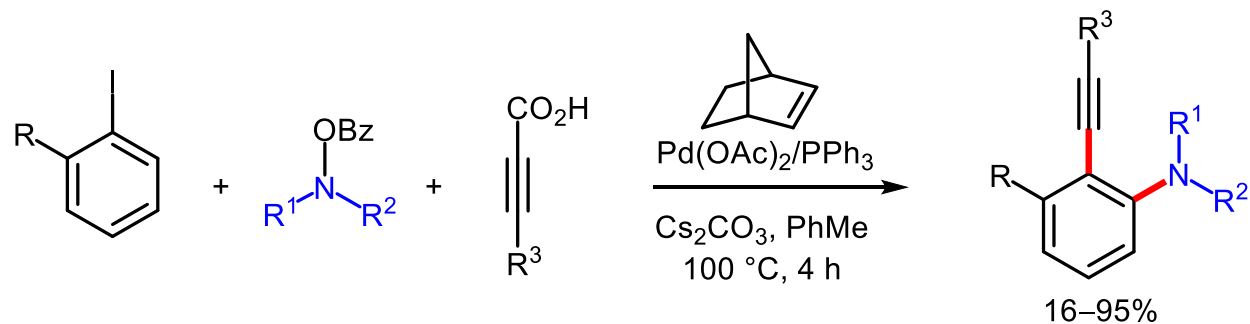
ortho-Amination/*ipso*-alkenylation and arylation



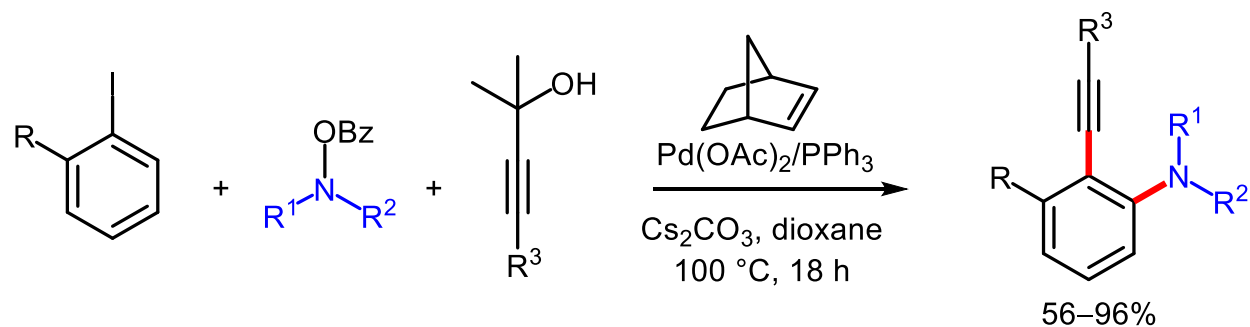
Z.-Y. Chen, C.-Q. Ye, H. Zhu, X.-P. Zeng, J.-J. Yuan, Chem. Eur. J. 2014, 20, 4237

C. Ye, H. Zhu, Z. Chen, J. Org. Chem. 2014, 79, 8900

ortho-Amination/*ipso*-Alkynylation

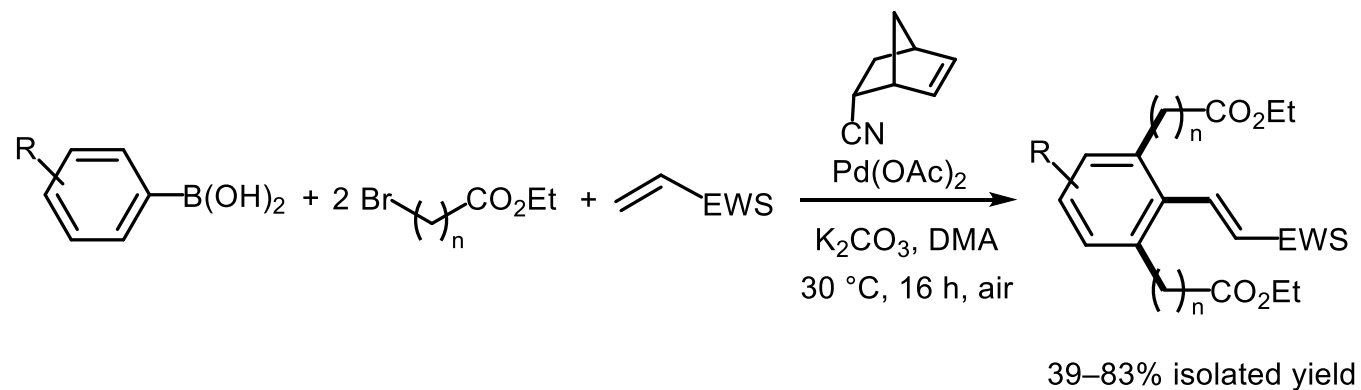
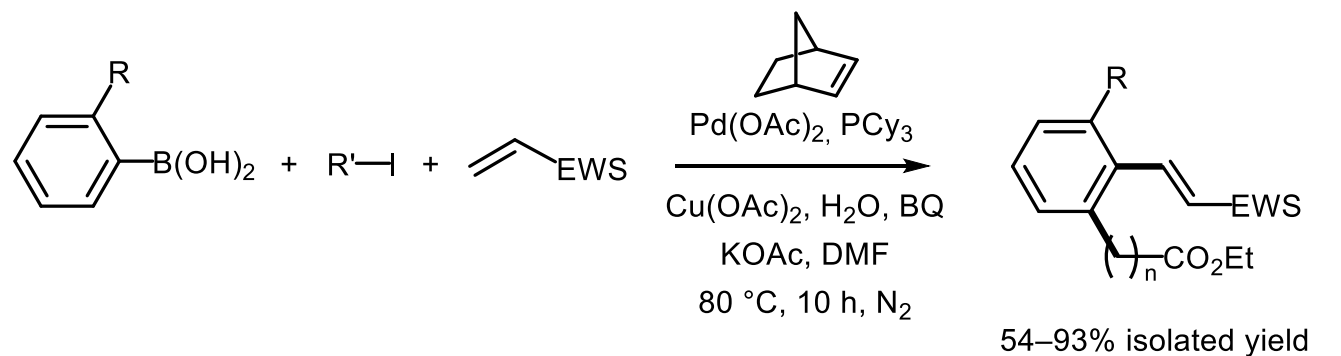


F. Sun, Z. Gu, *Org. Lett.* **2015**, *17*, 2222



S. Pan, X. Ma, D. Zhong, W. Chen, M. Liu, H. Wu, *Adv. Synth. Catal.* **2015**, *357*, 4927

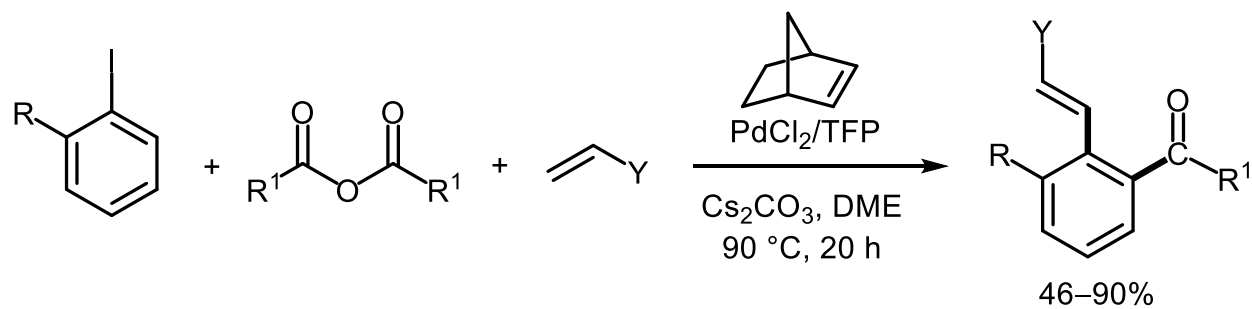
Aryl boronic acids as precursors of the aryl group



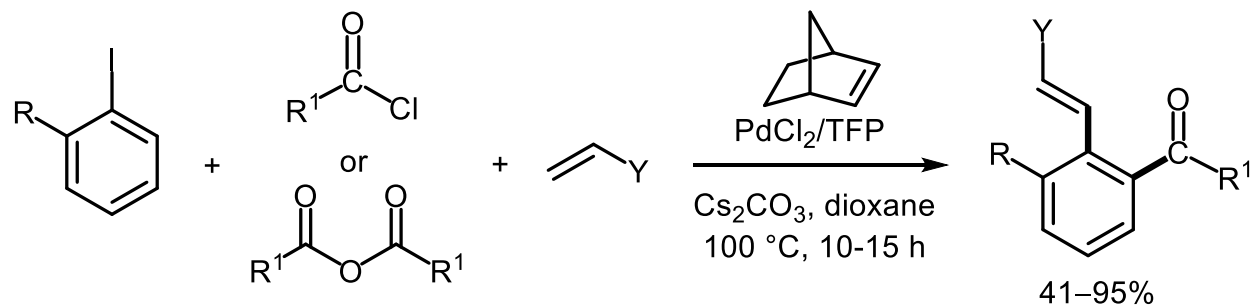
G.-F. Shi, C.-D. Shao, X.-T. Ma, Y.-C. Gu, Y.-H. Zhang, ACS Catal. 2018, 8, 3775.

S. Chen, Z.-S. Liu, T. Yang, Y. Hua, Z. Zhou, H.-G. Cheng, ACIE 2018, 57, 7161

ortho-Acylation/*ipso*-Alkenylation

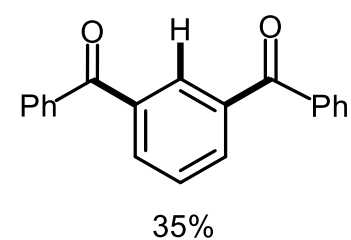
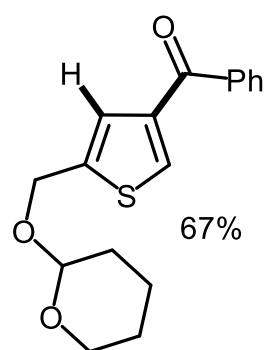
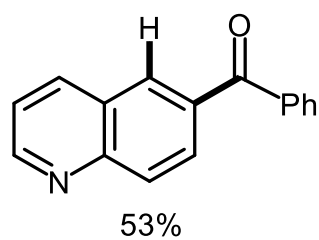
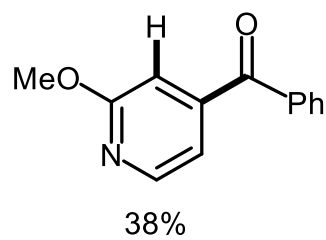
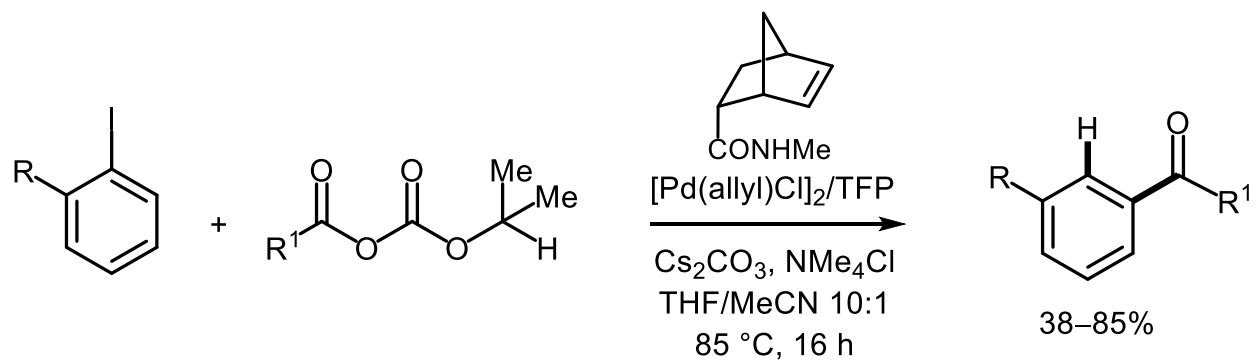


P.-X. Zhou, Y.-Y. Ye, et al., ACS Catal. 2015, 5, 4927

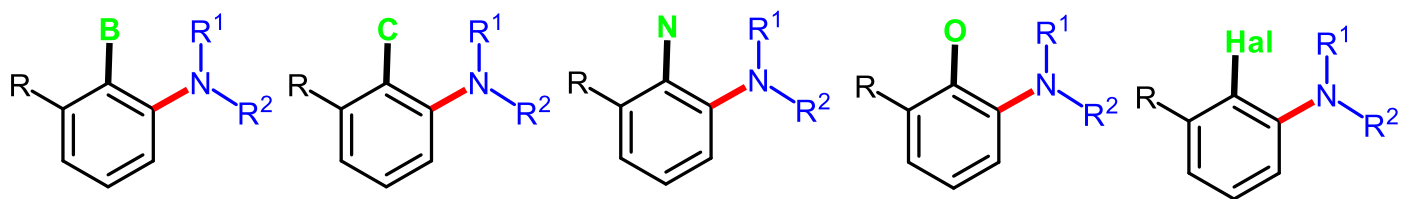
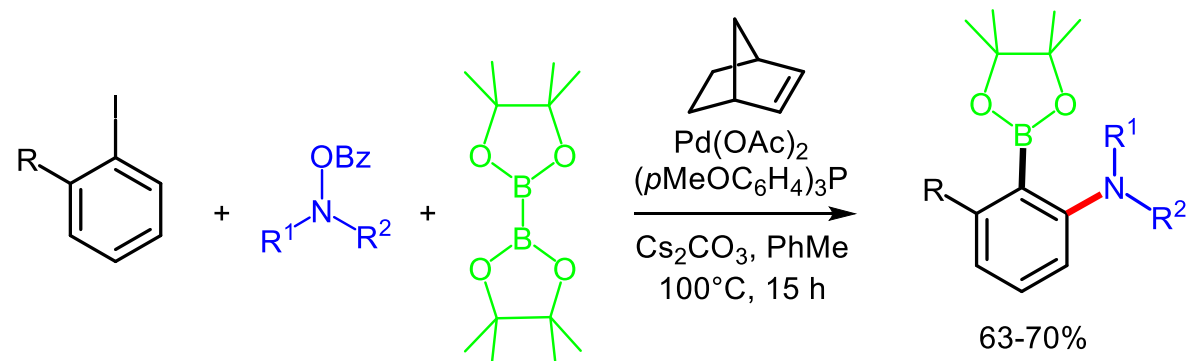


Y. Huang, R. Zhu, K. Zhao, Z. Gu, ACIE, 2015, 54, 12669

ortho-Acylation/*ipso*-Hydrogenolysis

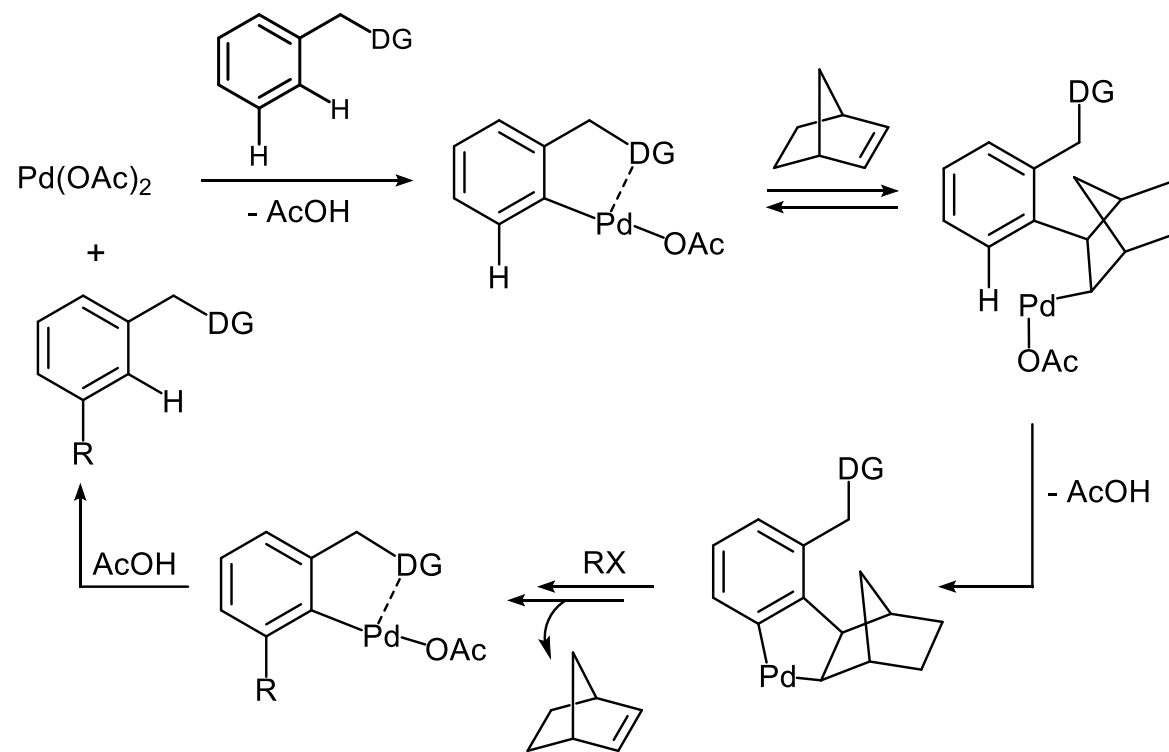


ortho-Amination/*ipso*-Borylation



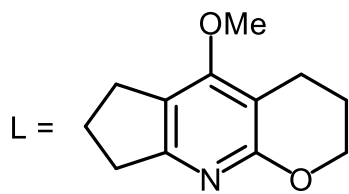
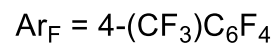
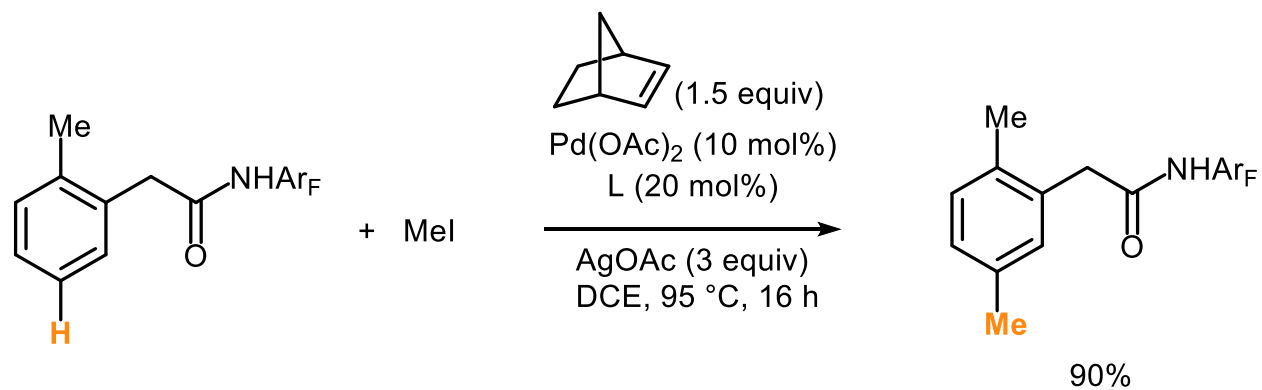
H. Shi, D. J. Babinski, T. Ritter, *J. Am. Chem. Soc.* **2015**, 137, 3775.

meta Selective Functionalization by two Consecutive *ortho*-Activation Steps

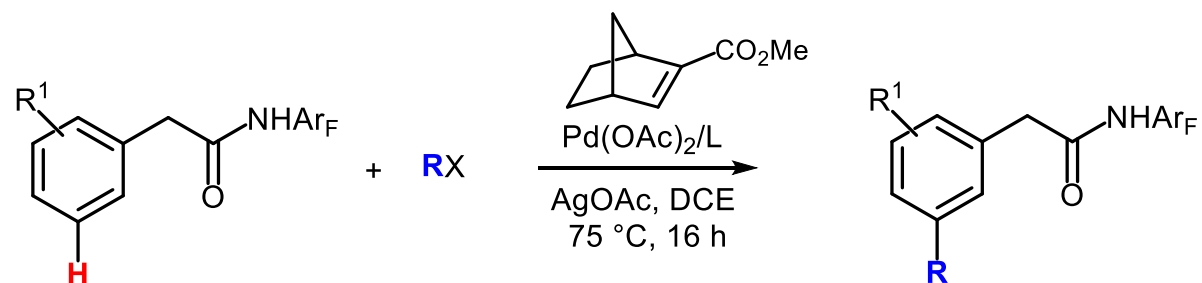


X.-C. Wang, W. Gong, L.-Z. Fang, R.-Y. Zhu, S. Li, K. M. Engle, J.-Q. Yu, *Nature* **2015**, 519, 334
Z. Dong, J. Wang, G. Dong, *J. Am. Chem. Soc.* **2015**, 137, 5887

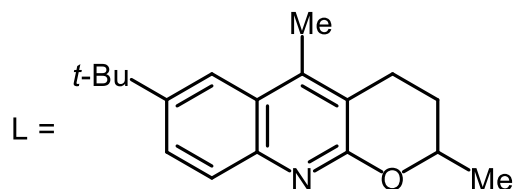
Norbornene as a «Transient Mediator» for *meta* C–H Functionalization



A 2-Substituted Norbornene for *meta* C–H Functionalization



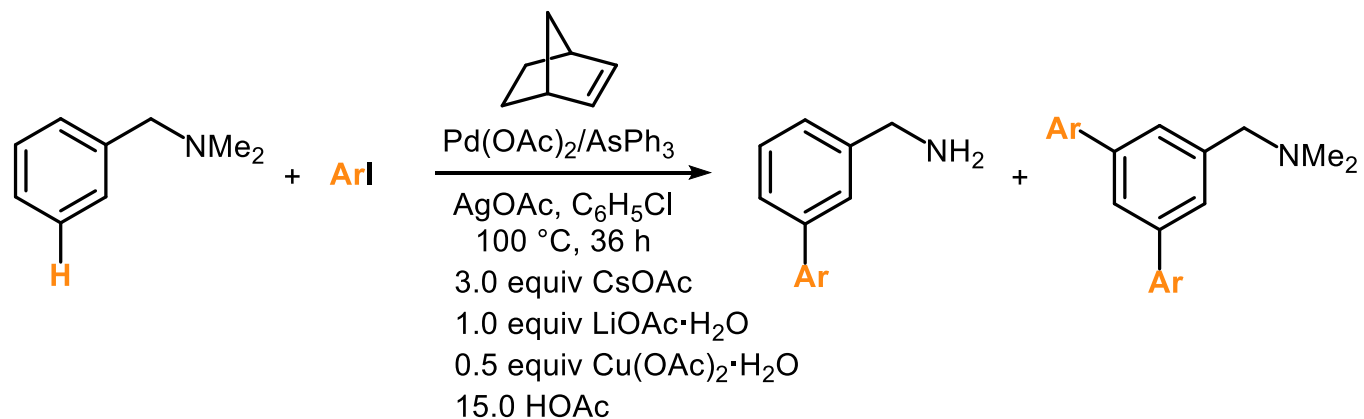
Ar_F = 4-(CF₃)C₆F₄



RX = primary Alk–I
52-93%

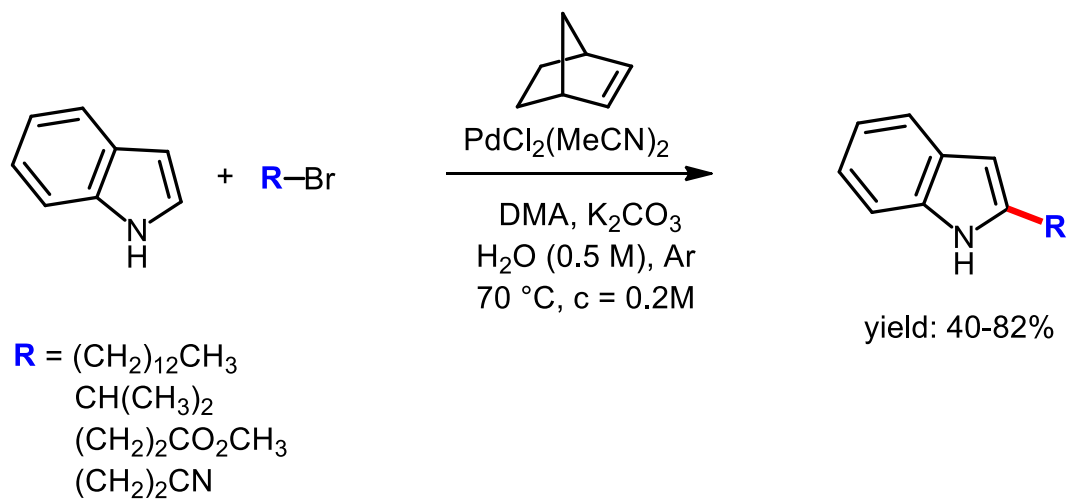
RX = Ar–I
57-87%

Amine-Directed *meta*-Selective C–H Arylation via Pd/Norbornene Catalysis



Z. Dong, J. Wang, G. Dong, *J. Am. Chem. Soc.* **2015**, 137, 5887

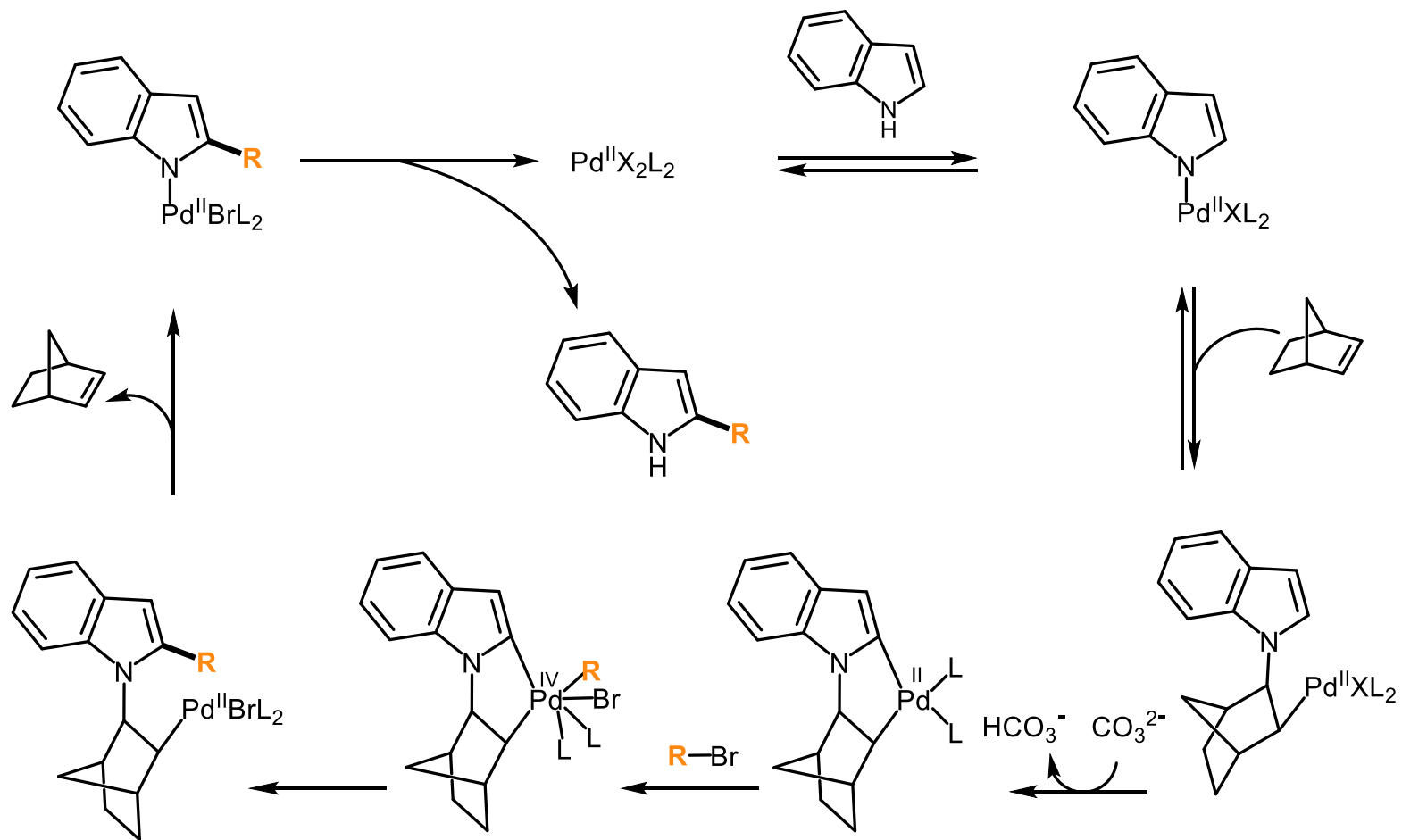
Pd(II)/Pd(IV)/Norbornene Catalysis for 2-Alkylation of Indoles



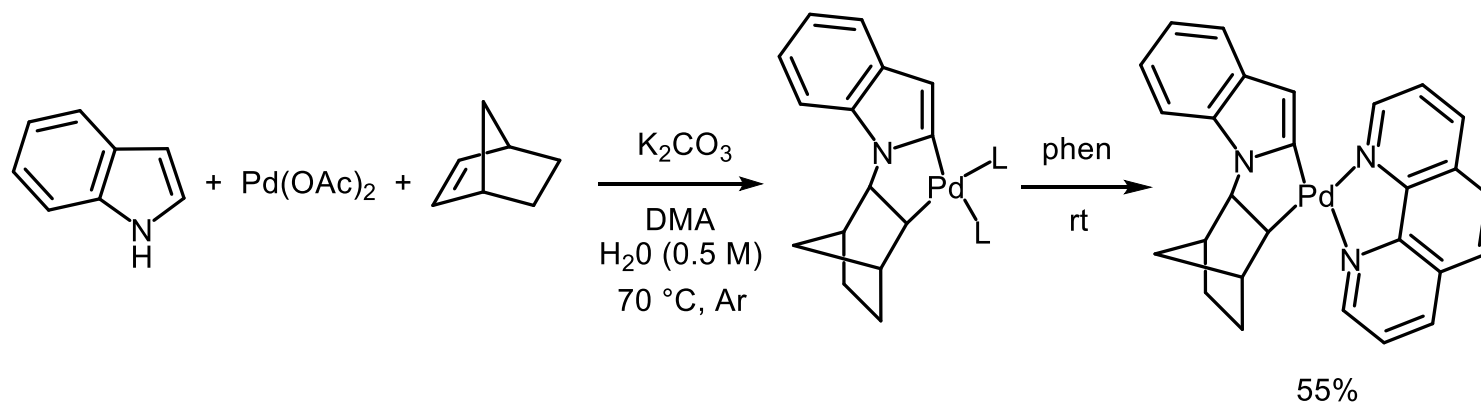
L. Jiao, T. Bach, *JACS*, **2011**, *133*, 12990

L. Jiao, E. Herdtweck, T. Bach, *JACS*, **2012**, *134*, 14563

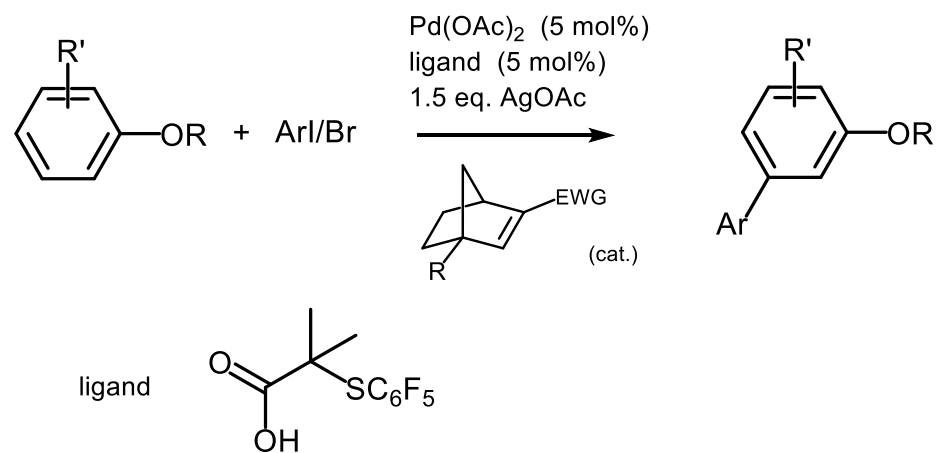
Proposed pathway for 2-alkylation of indole



Separation and Characterization of the Key Palladacycle Intermediate

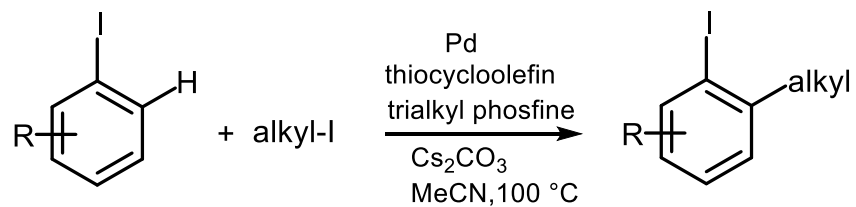


S,O-Ligand promoted *meta*-C-H arylation of anisole derivatives via Pd/norbornene catalysis



Compatible with EDG and EWG
Compatible with *ortho*-substituted anisoles

...and finally *ortho*-alkylation of iodoarenes



Y.-X. Zeng, L. Jiao, Nat. Synth. 2022, 1, 180; F.-Y. Wang, Y.-X. Li, L. Jiao, JACS, 2023, 145, 4871;
X.-X. Wang, L. Jiao, JACS, 2024, 9 September

Escape from Palladium: Nickel-catalyzed Catellani-annulation react

