LITERATURE REPORT

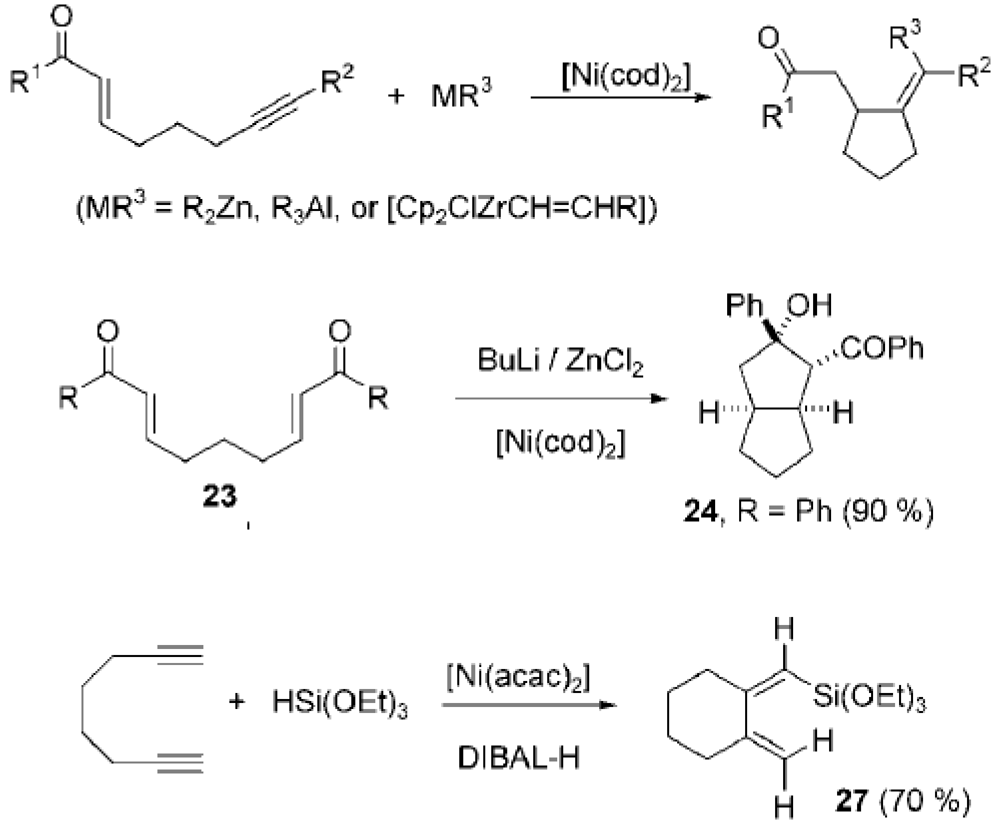
Nickel-Catalyzed Reductive Cyclizations and Couplings of Alkyne and Aldehyde

Reporter: He Zhiqi
Supervisor: Prof. Yong Huang
2015.05.25

Contents

J. Montgomery, *et al. Acc. Chem. Res*.. **2015**, *48*, ASAP.
T. F. Jamison, *et al. Acc. Chem. Res*.. **2015**, *48*, ASAP.
S. Ogoshi, *et al. Acc. Chem. Res*.. **2015**, *48*, ASAP.

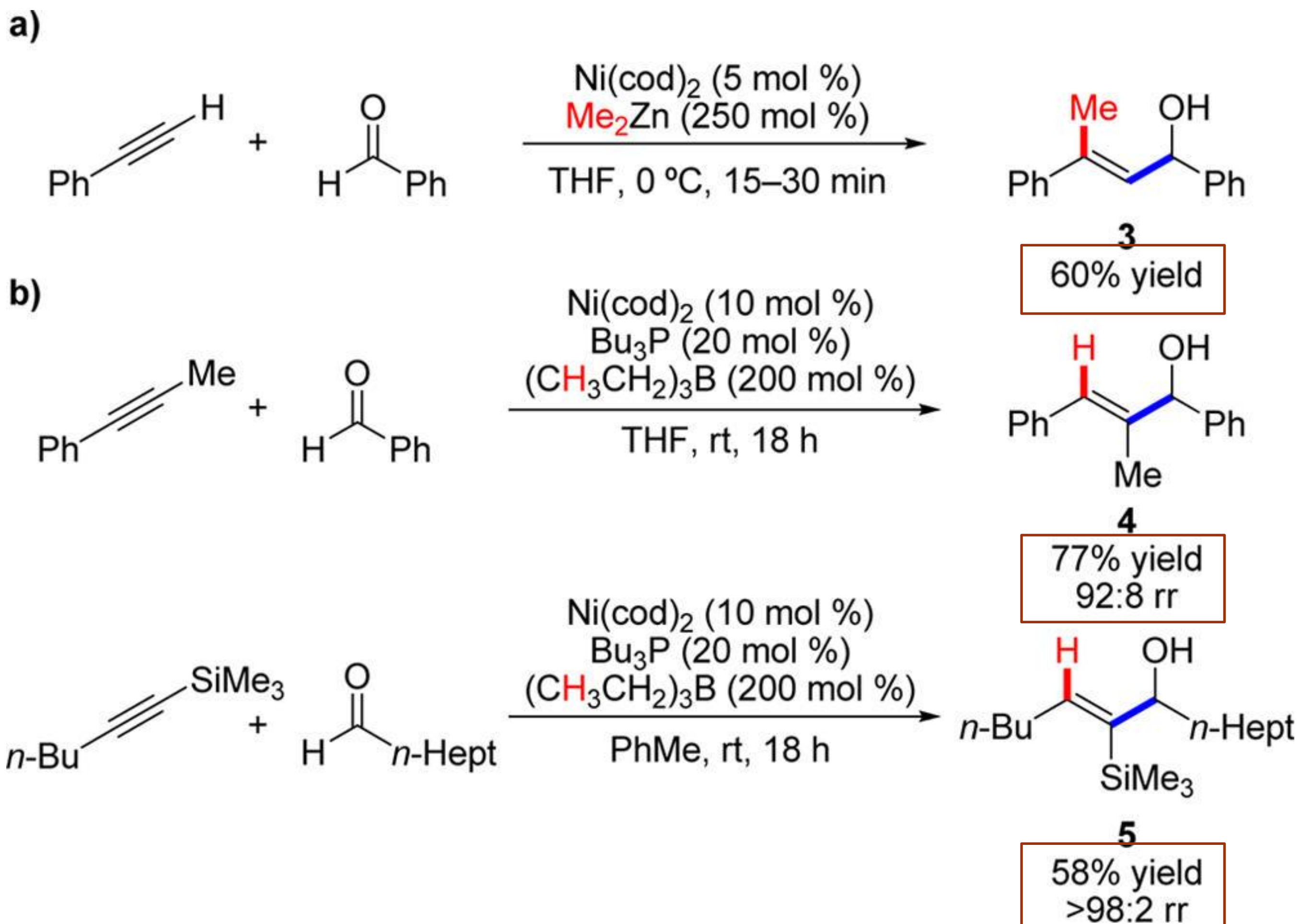
1. Introduction:



J. Montgomery, *et al. Angew. Chem., Int. Ed.* **2004**, *43*, 3890.

2. Reductive Coupling of Alkyne and Aldehyde

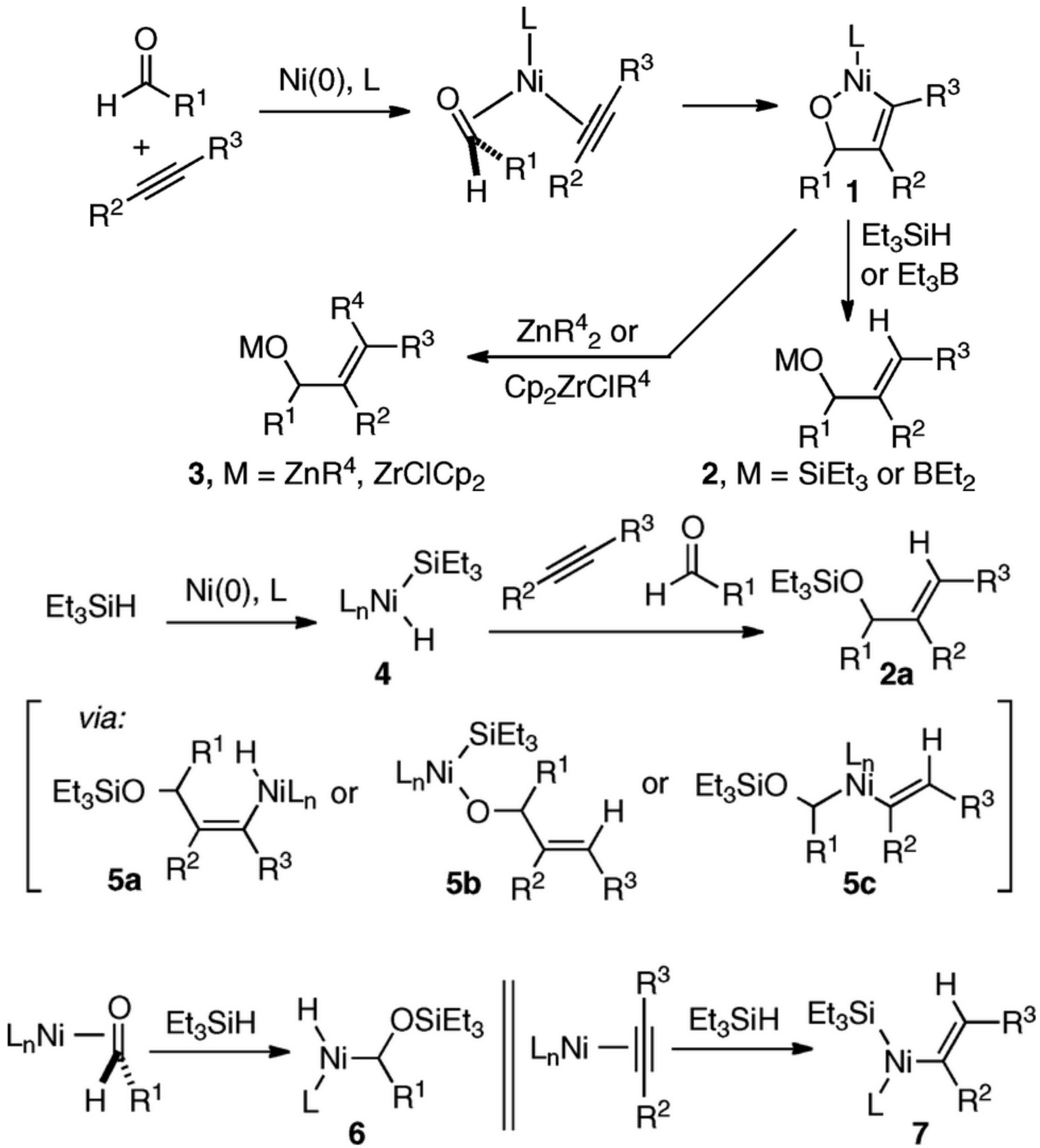
Early studies:

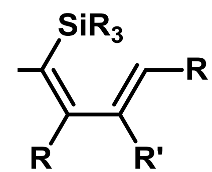


J. Montgomery, *et al. J. Am. Chem. Soc.* **1997**, *119*, 9065.

T. F. Jamison, *et al. Org. Lett.* **2000**, *2*, 4221.

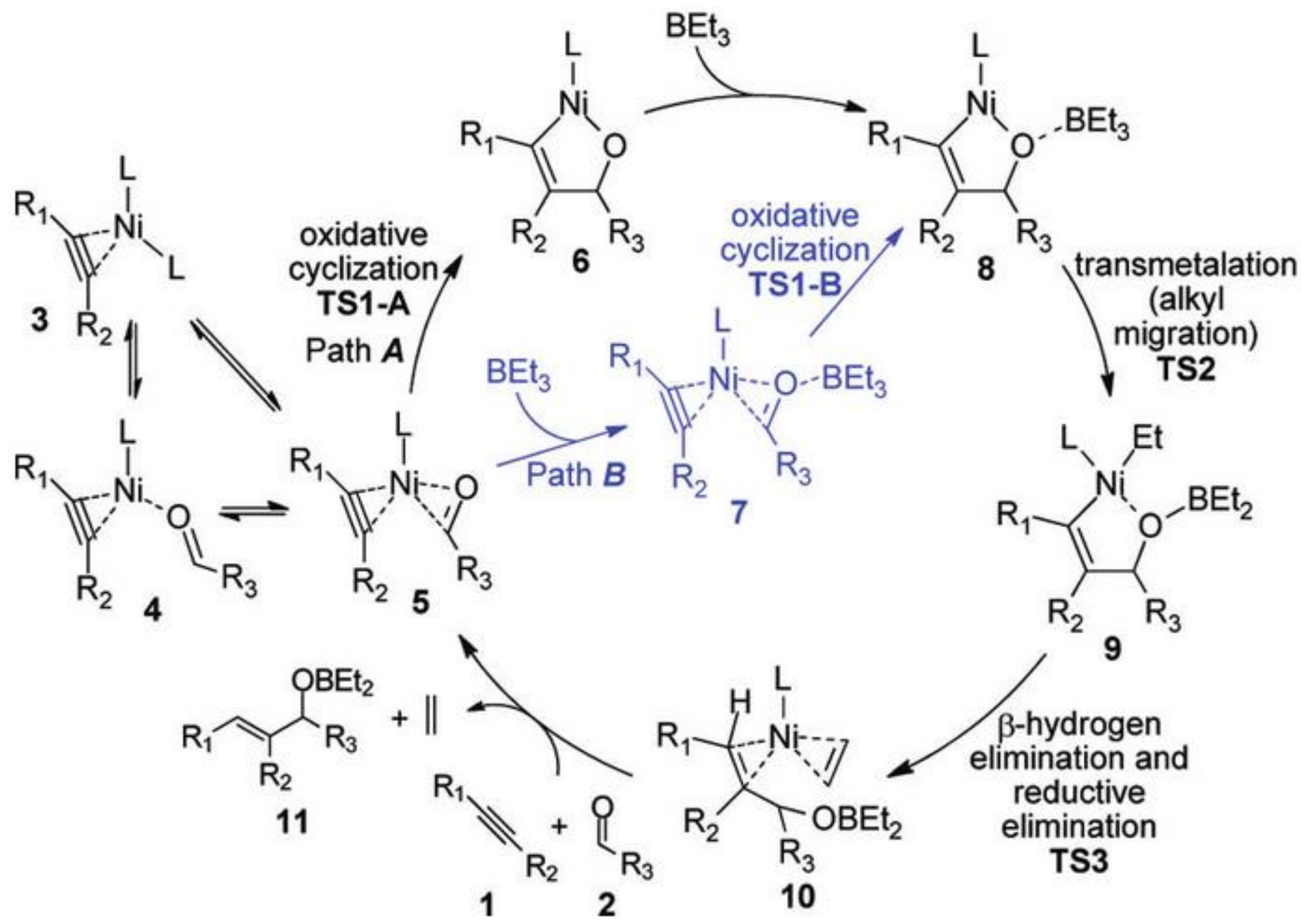
Mechanism discussion:



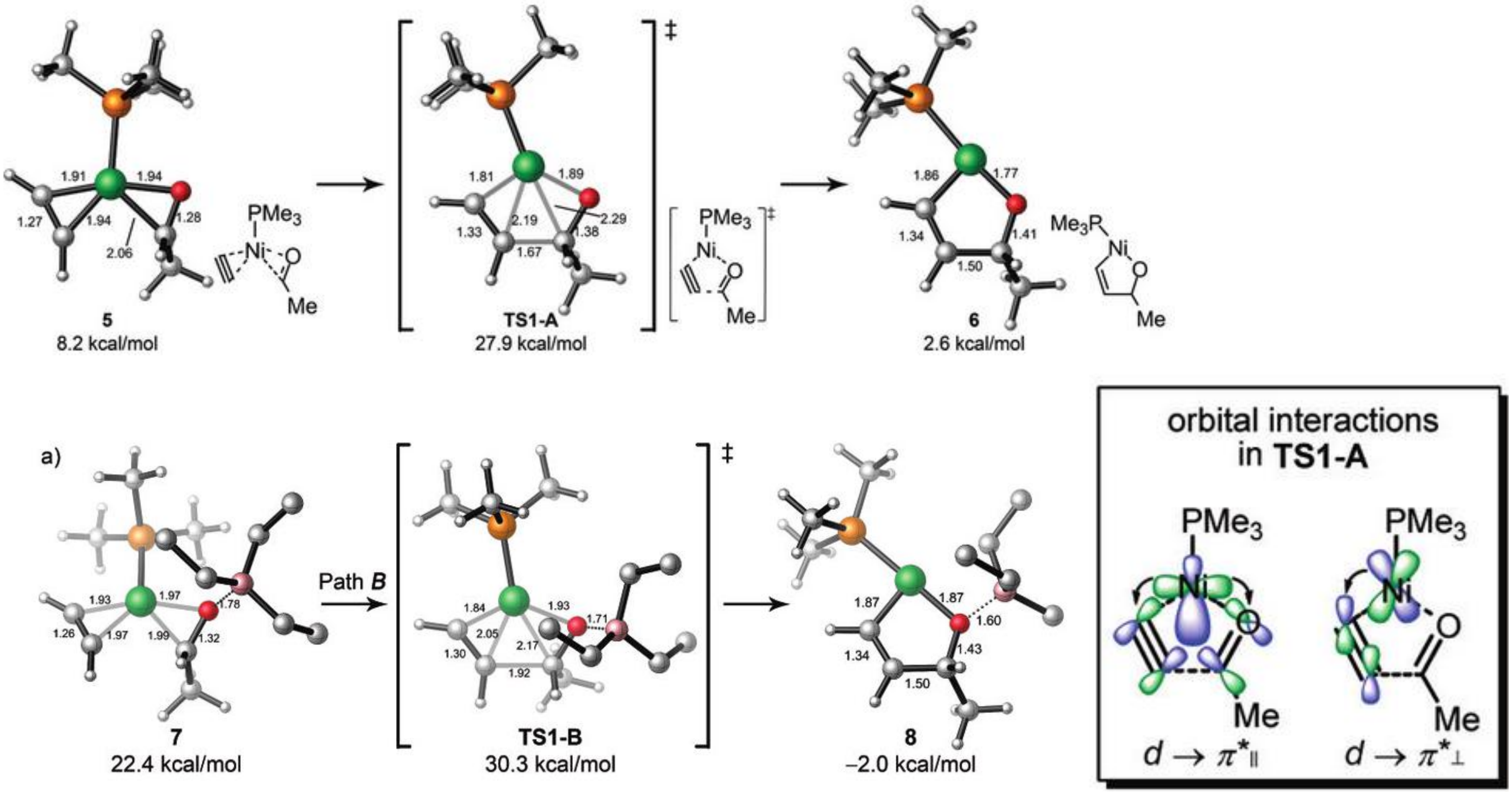


J. Montgomery, *et al. J. Am. Chem. Soc.* **1997**, *119*, 9065.

Computational study:

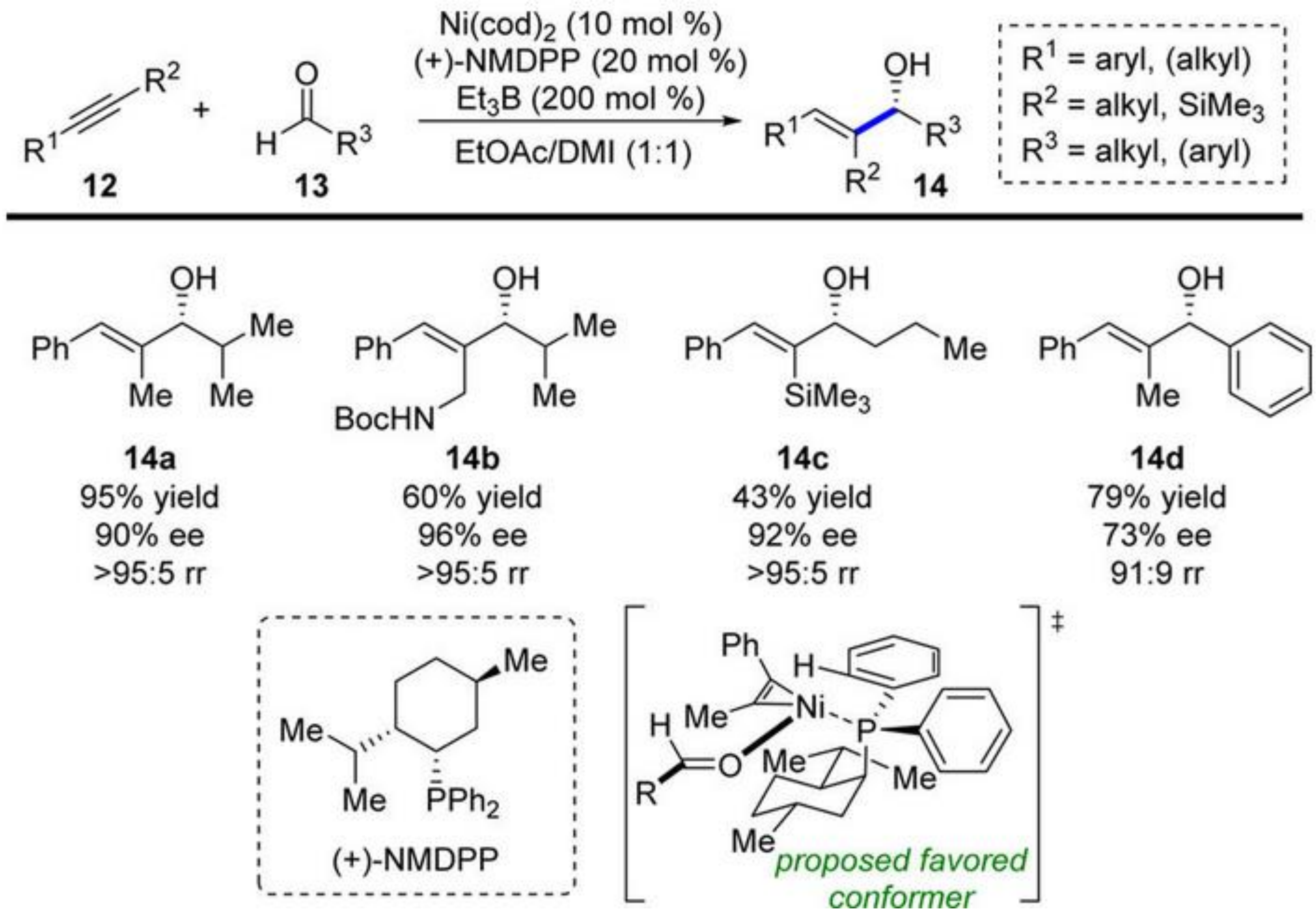


K. N. Houk and T. F. Jamison, *et al. J. Am. Chem. Soc.* **2009**, *131*, 6654.



K. N. Houk and T. F. Jamison, *et al. J. Am. Chem. Soc.* **2009**, *131*, 6654.

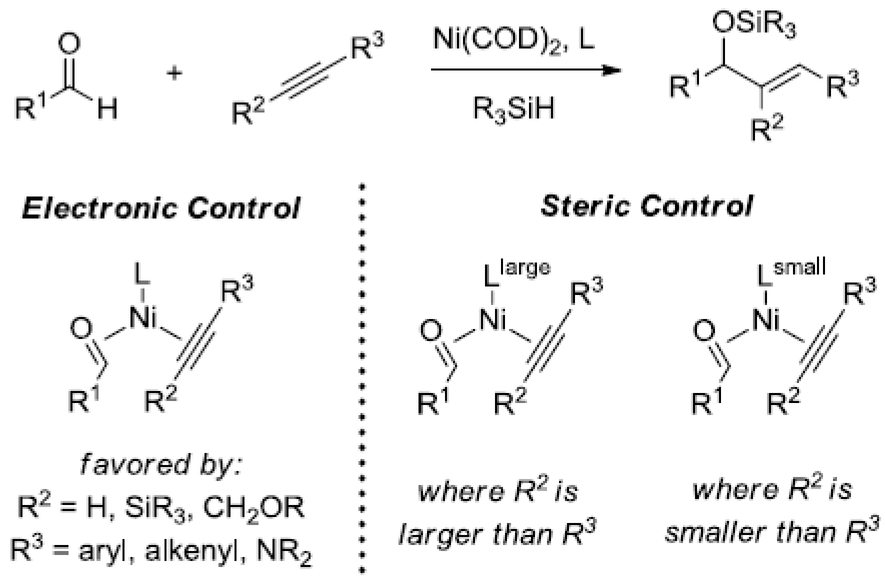
Enantioselective alkyne-aldehyde reductive coulping:



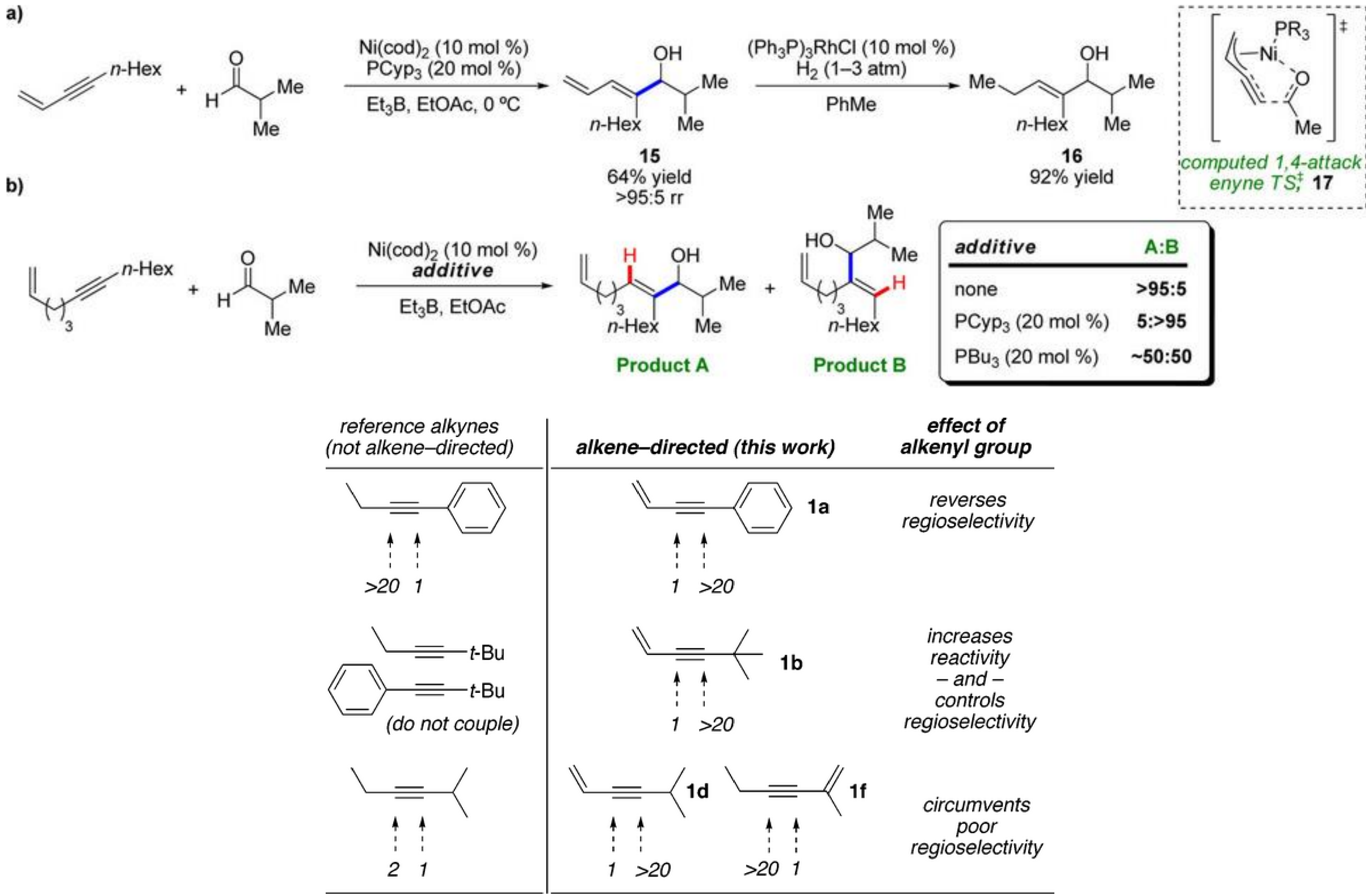
T. F. Jamison, *et al. J. Am. Chem. Soc.* **2003**, *125*, 3442.

T. F. Jamison, *et al. J. Org. Chem.* **2003**, *68*, 156.

Regiocontrol strategies:

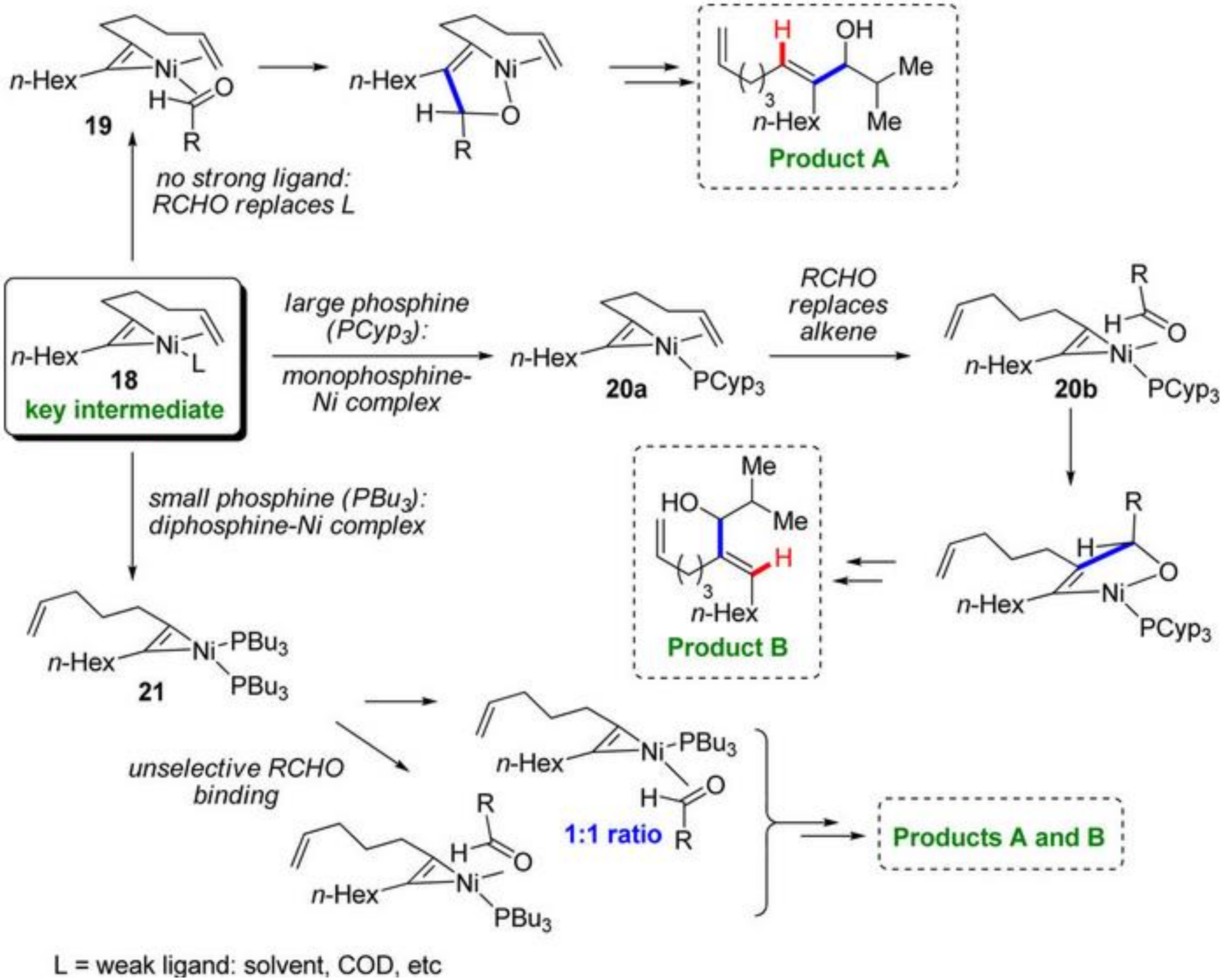


Alkene directing effects:



T. F. Jamison, *et al. J. Am. Chem. Soc.* **2004**, *126*, 4130.

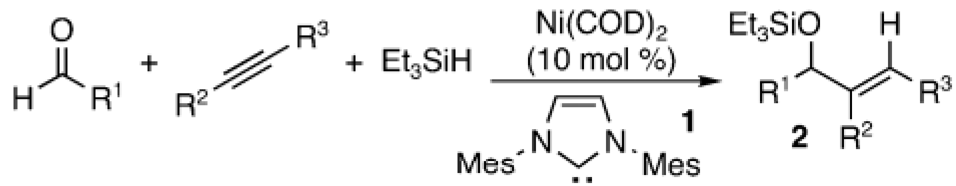
Alkene directing effects: mechanism study



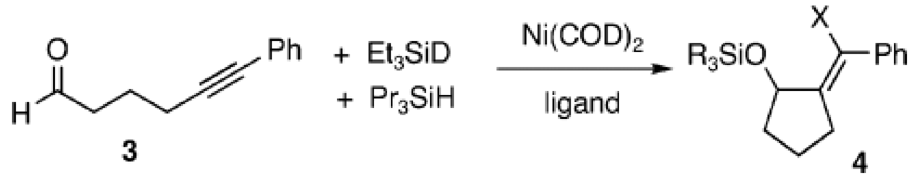
T. F. Jamison, *et al. J. Am. Chem. Soc.* **2004**, *126*, 4130.

K. N. Houk and T. F. Jamison, *et al. J. Am. Chem. Soc.* **2010**, *132*, 2050.

NHCs ligand effects:



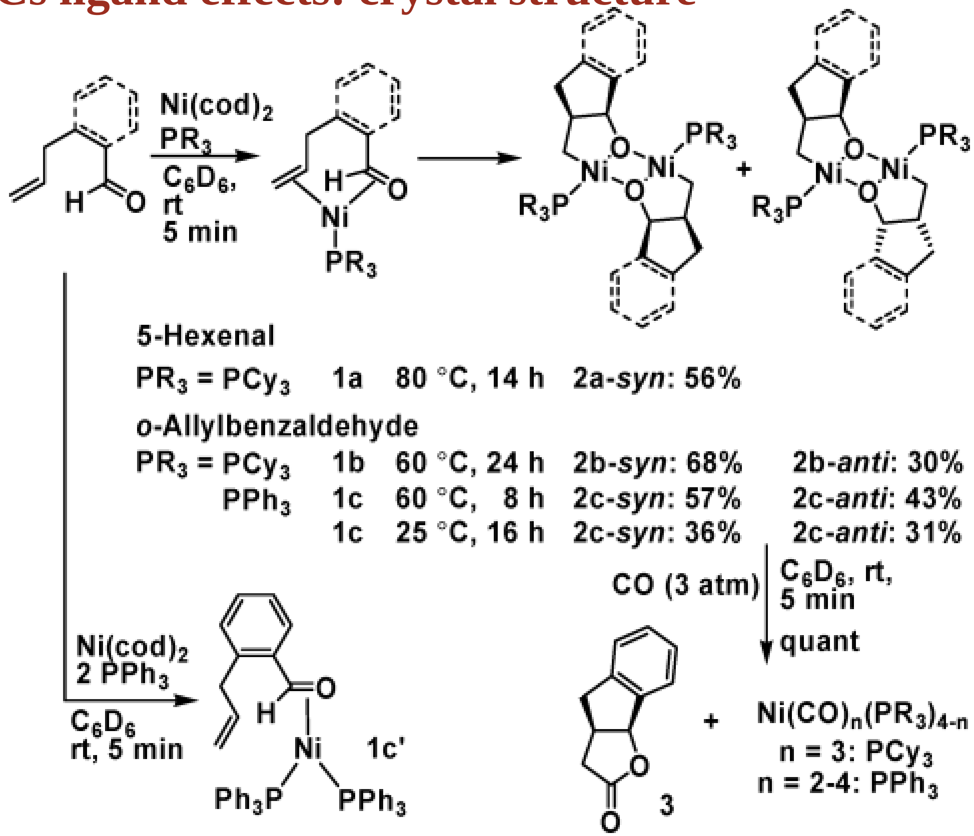
entry	R^1	R^2	R^3	yield (regioselectivity)
1	Ph	CH_3	Ph	84% (>98:2)
2	C_6H_{13}	CH_3	Ph	82% (>98:2)
3	Ph	H	C_6H_{13}	71% (>98:2)
4	Ph	H	Ph	72% (>98:2)
5	Ph	CH_3	C_4H_9	84% (1.3:1)
6	*s*-Bu	CH_3	Ph	81% (>98:2)[c]
7	$C_6H_4OCH_3$	CH_3	Ph	66% (>98:2)
8	Ph	Ph	$C(CH_3){=}CH_2$	84% (>98:2)
9	Ph	H	$CH{=}CHC_6H_{13}$	56% (>98:2)
10	Ph	H	$(CH_2)_4OH$	72% (>98:2)[d]

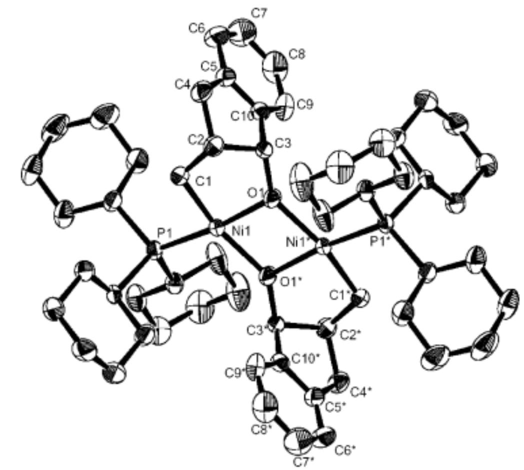


			relative %	
R	X	product	from 1	from PBu_3
Et	H	**4a**	<2	25
Et	D	**4b**	55	34
Pr	H	**4c**	41	23
Pr	D	**4d**	<2	18

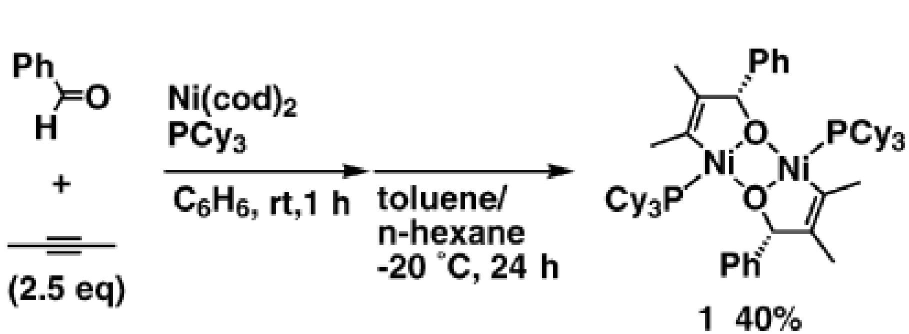
J. Montgomery, *et al. J. Am. Chem. Soc.* **2004**, *126*, 3698.

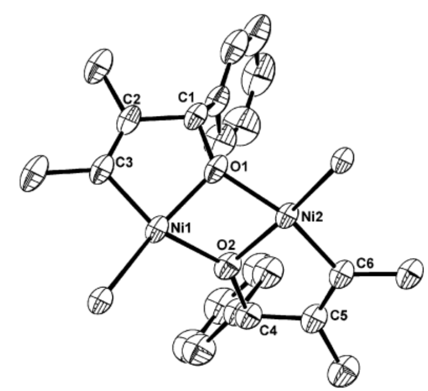
NHCs ligand effects: crystal structure





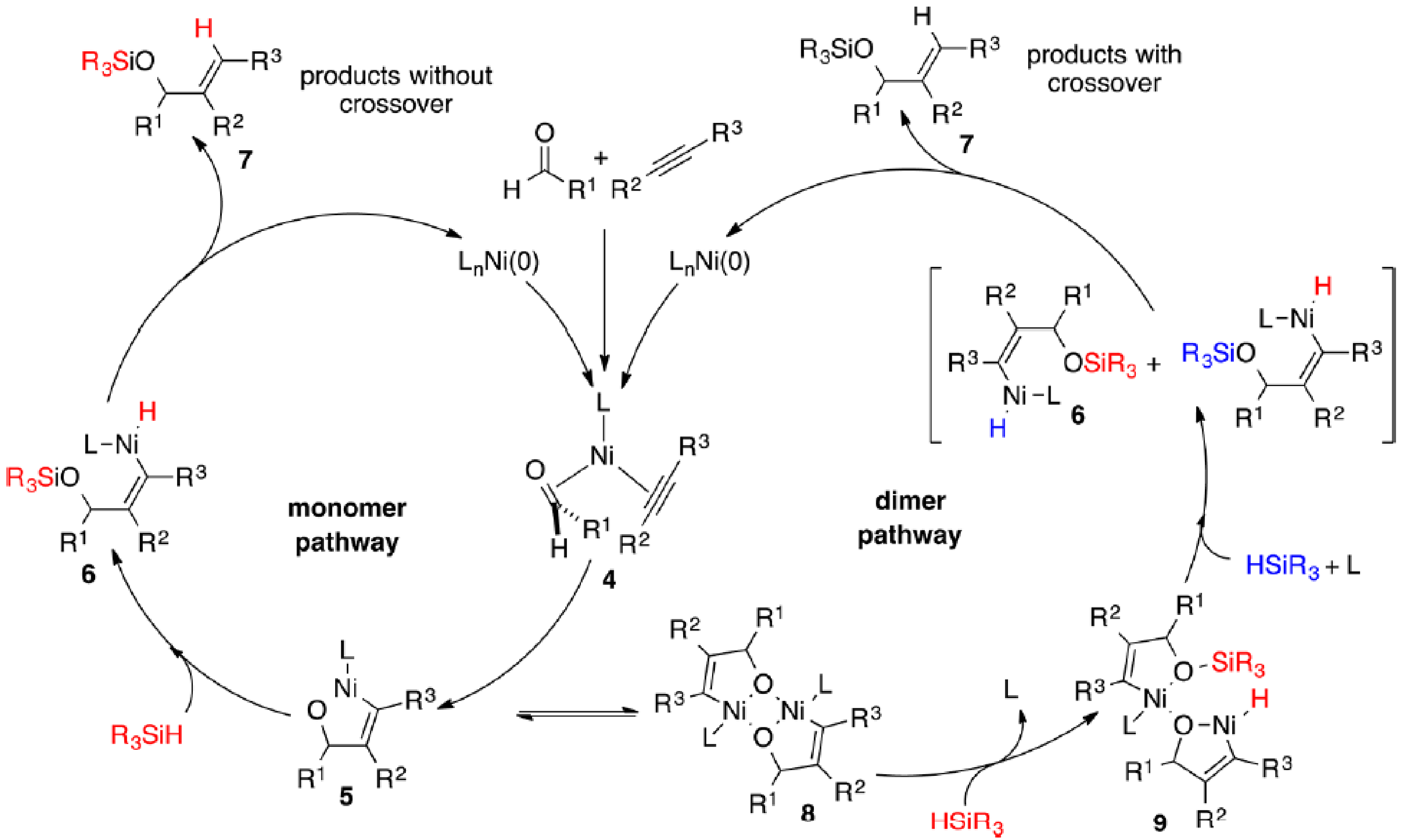
S. Ogoshi, *et al. J. Am. Chem. Soc.* **2004**, *126*, 11802.



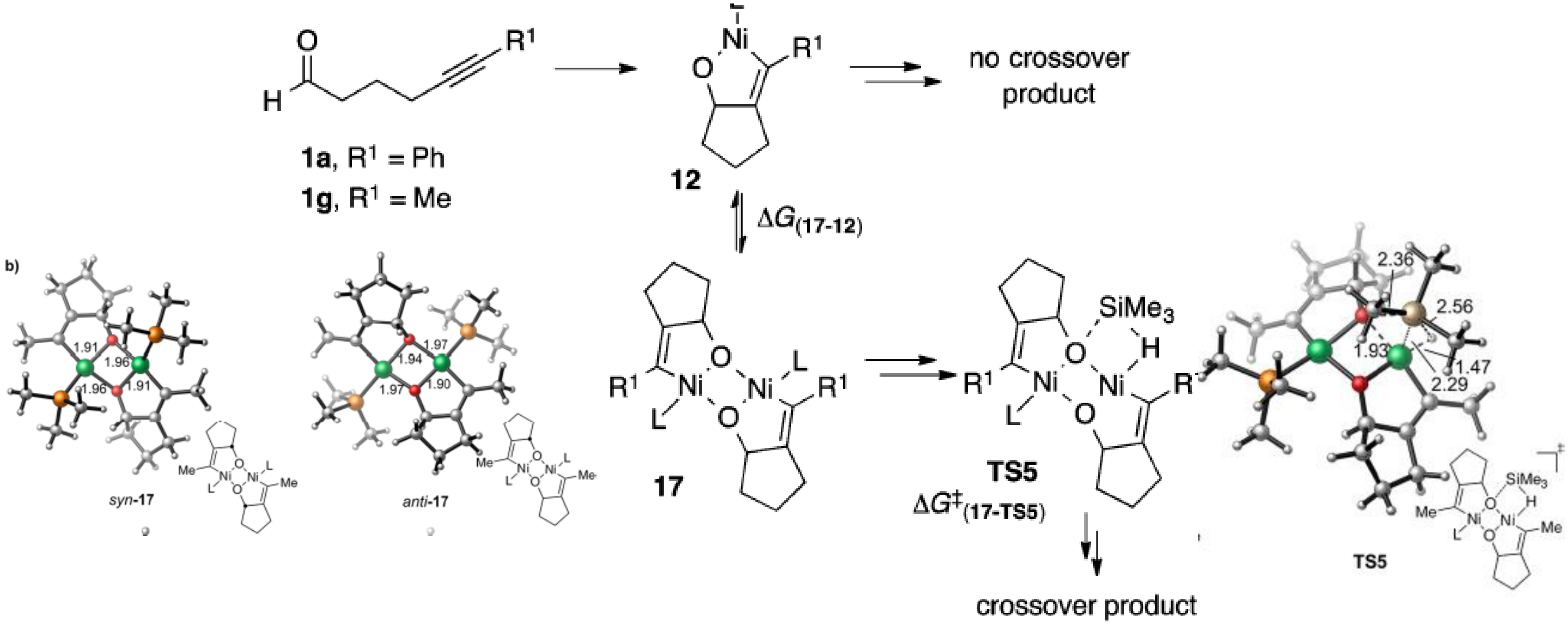


S. Ogoshi, *et al. Chem. Comm.* **2008**, *44*, 1347.

NHCs ligand effects: computational study



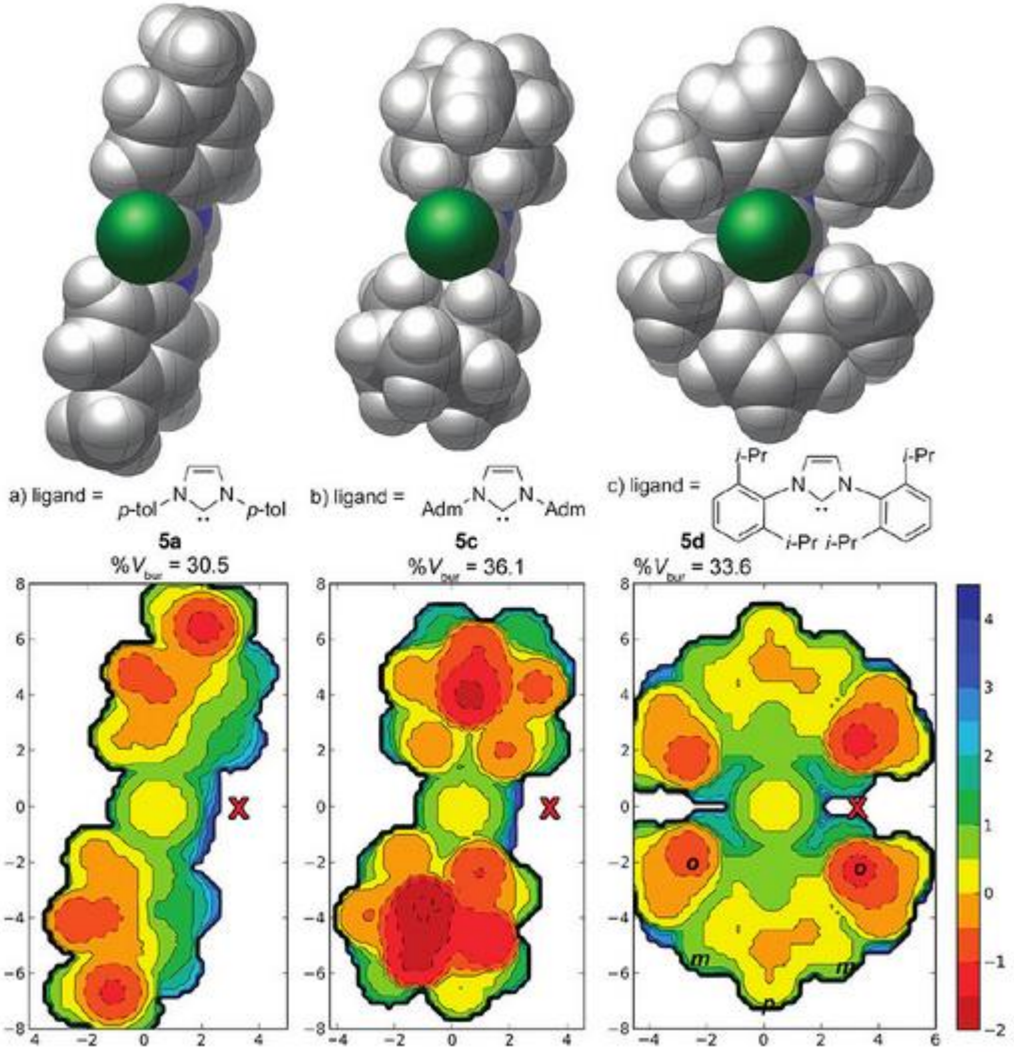
K. N. Houk and J. Montgomery, *et al. J. Am. Chem. Soc.* **2014**, *136*, 17495.



entry	ligand	ynal	$\Delta G_{17\rightarrow12}$	$\Delta G^{\ddagger}_{17\rightarrow TS5}$
1	PMe_3	1g	20.3	25.9
2	P(*i*-Pr)$_3$	1g	15.2	24.2
3	IPh	1g	23.7	44.9
4	IMes	1g	14.0	36.1
5	PMe_3	1a	22.3	31.8

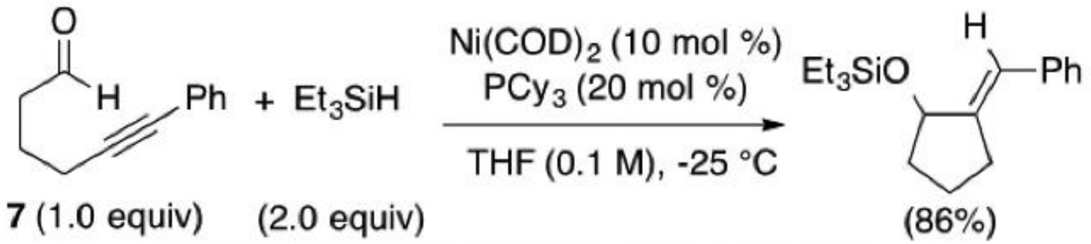
[a] Energies are in kilocalories per mole and with respect to 17.

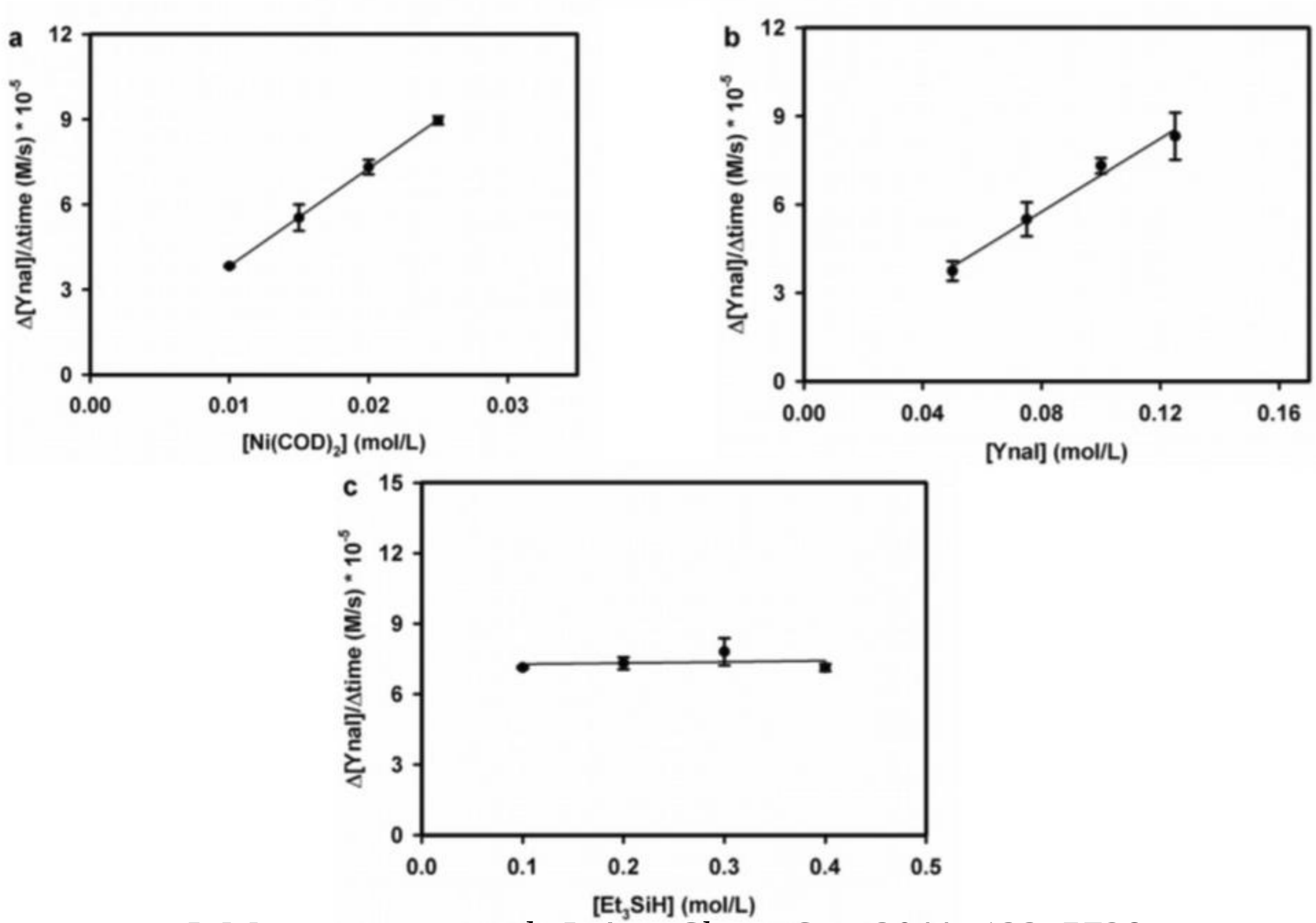
K. N. Houk and J. Montgomery, *et al. J. Am. Chem. Soc.* **2014**, *136*, 17495.



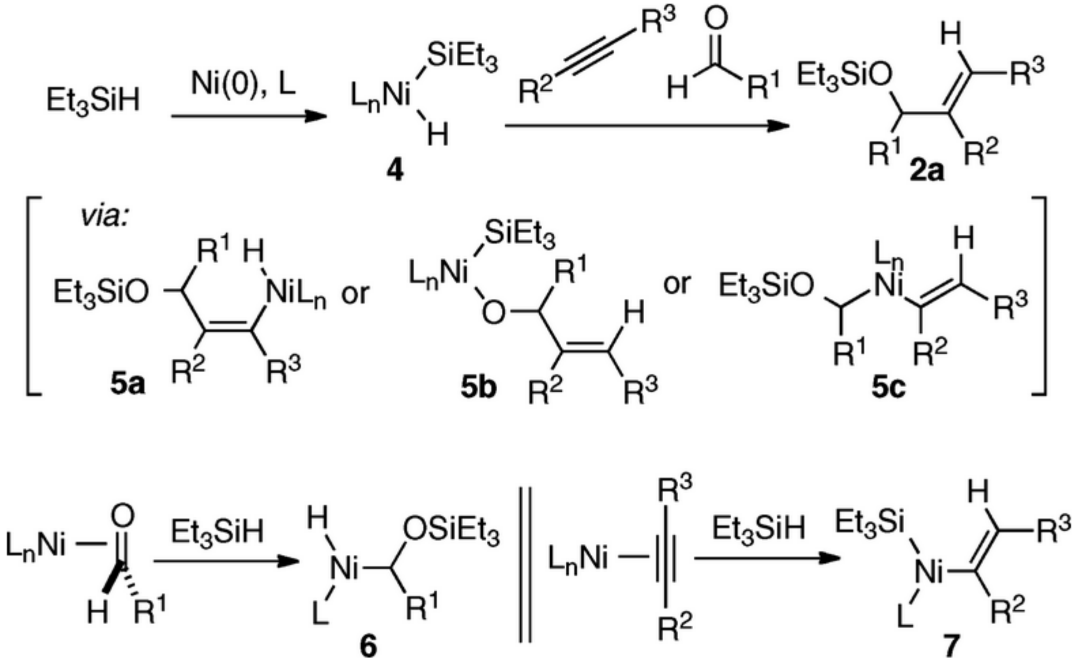
K. N. Houk and J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 6956.

Kinetic study:

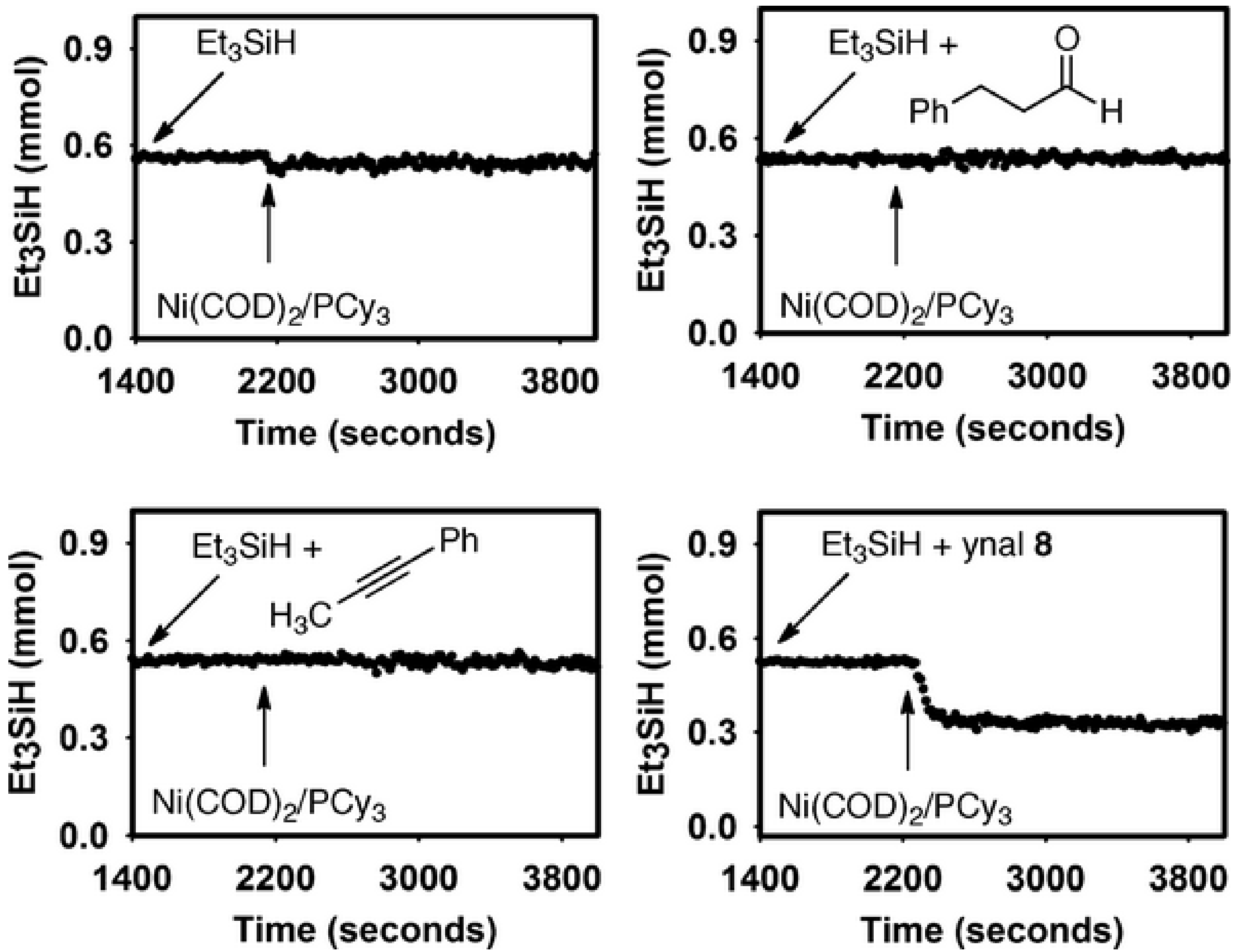




J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 5728.

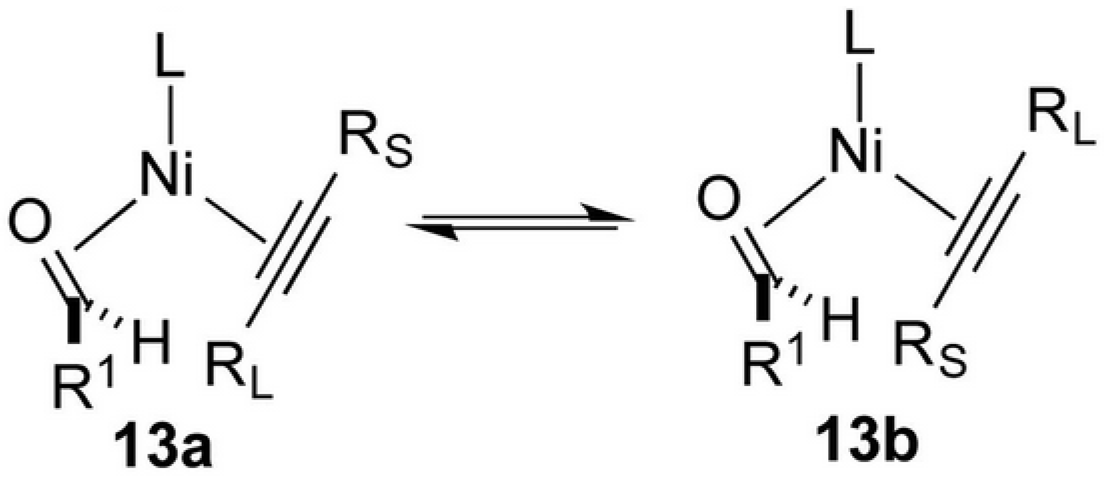


J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 5728.

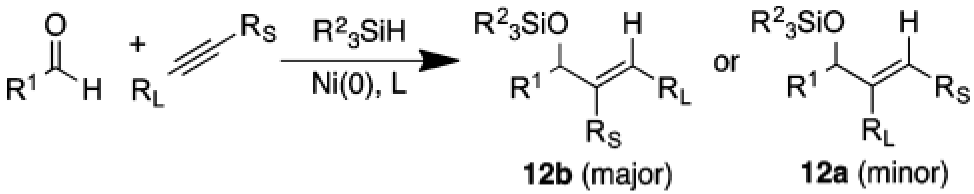


J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 5728.

A general strategy for regiocontrol:

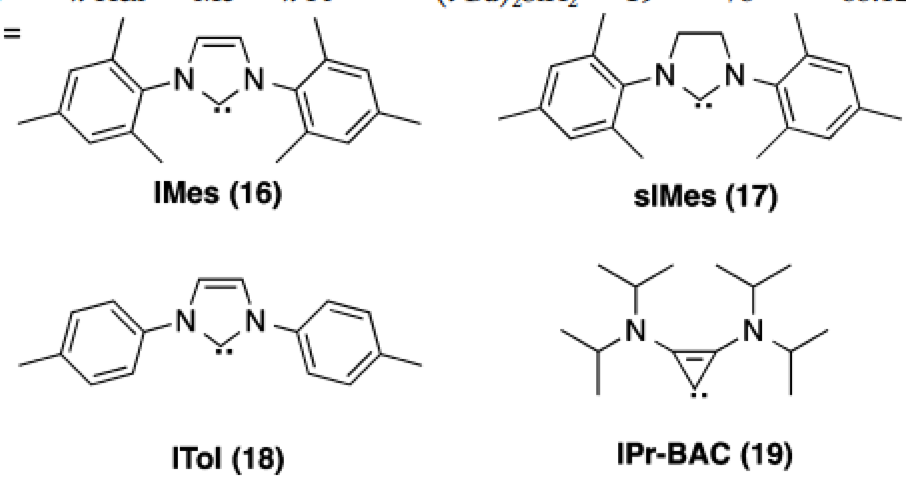


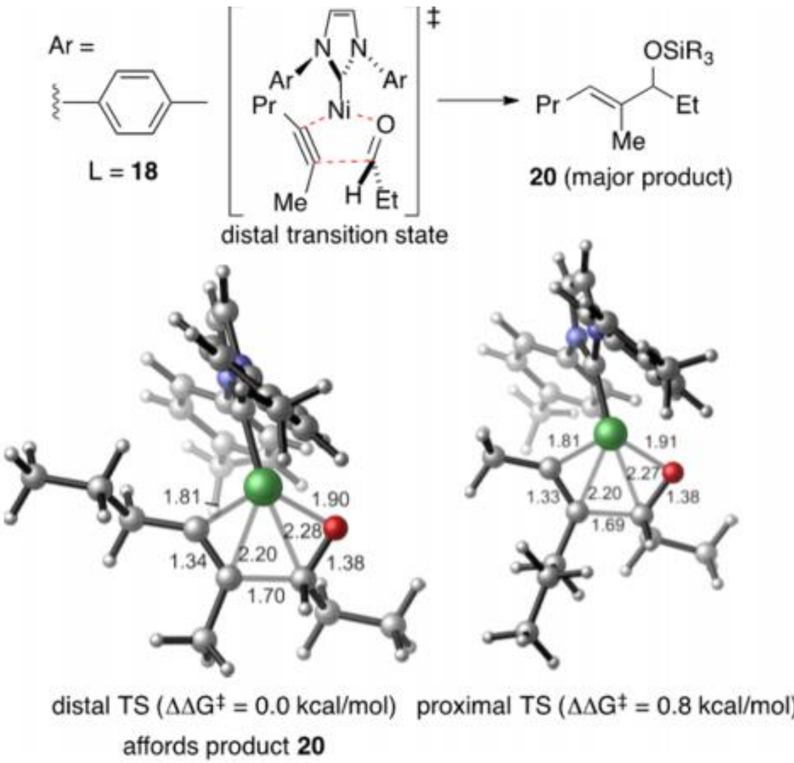
A general strategy for regiocontrol: small ligand protocol



entry	R^1	R^S	R^L	R^2_3SiH	L	% yield	12b/12a
1	*n*-Hex	H	*i*-Pr	$(i\text{-Pr})_3SiH$	**16**	74	>98:2
2	Ph	Me	Ph	$(i\text{-Pr})_3SiH$	**16**	74	>98:2
3	*n*-Hex	Me	*c*-hexenyl	$(i\text{-Pr})_3SiH$	**16**	99	97:3
4	*n*-Hex	Me	*n*-Pr	$(i\text{-Pr})_3SiH$	**16**	83	67:33
5	*n*-Hex	Me	*n*-Pr	$(i\text{-Pr})_3SiH$	**17**	73	61:39
6	*n*-Hex	Me	*n*-Pr	$(i\text{-Pr})_3SiH$	**18**	18	87:13
7	*n*-Hex	Me	*n*-Pr	$(t\text{-Bu})_2SiH_2$	**19**	78	88:12

L =

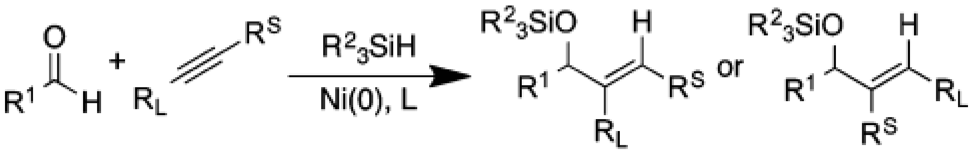




J. Montgomery, *et al. J. Am. Chem. Soc.* **2010**, *132*, 6304.

K. N. Houk and J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 6956.

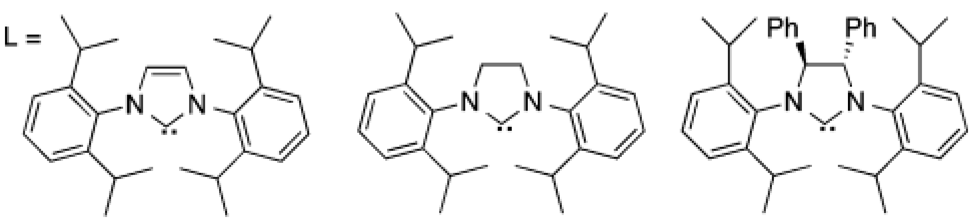
A general strategy for regiocontrol: large ligand protocol



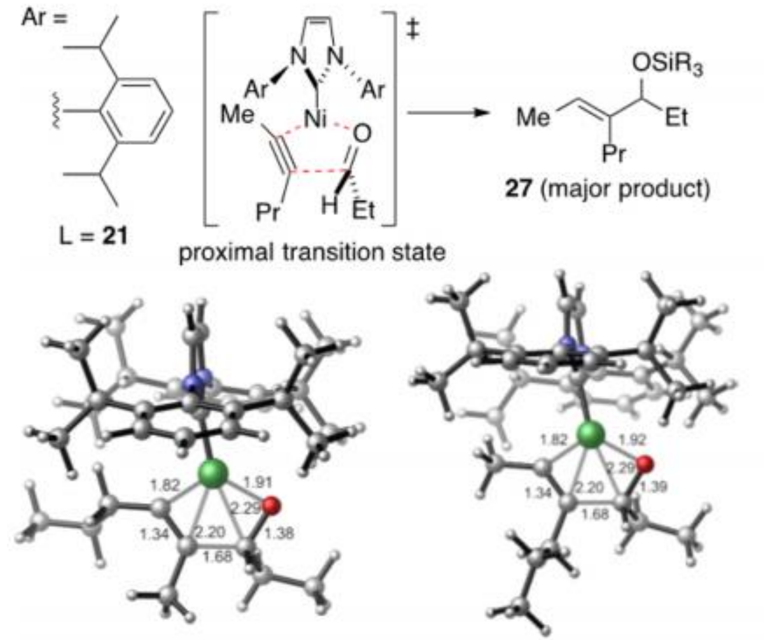
12a (major) **12b** (minor)

entry	R^1	R^L	R^S	R^2_3SiH	L	% yield	12a/12b
1	*n*-Hex	*n*-Pr	Me	$(i\text{-Pr})_3SiH$	**16**	83	67:33
2	*n*-Hex	*n*-Pr	Me	$(i\text{-Pr})_3SiH$	**21**	84	80:20
3	*n*-Hex	*n*-Pr	Me	$(i\text{-Pr})_3SiH$	**22**	85	93:7
4	*n*-Hex	*n*-Pr	Me	Et_3SiH	**23**	94	94:6
5	*n*-Hex	*i*-Pr	H	$(i\text{-Pr})_3SiH$	**22**	40	41:59[a]
6	*n*-Hex	*i*-Pr	H	Et_3SiH	**23**	76	95:5
7	Ph	Ph	Me	Et_3SiH	**22**	65	58:42
8	Ph	Ph	Me	Et_3SiH	**23**	96	69:31[a]

[a]Data from H. A. Malik thesis, University of Michigan.



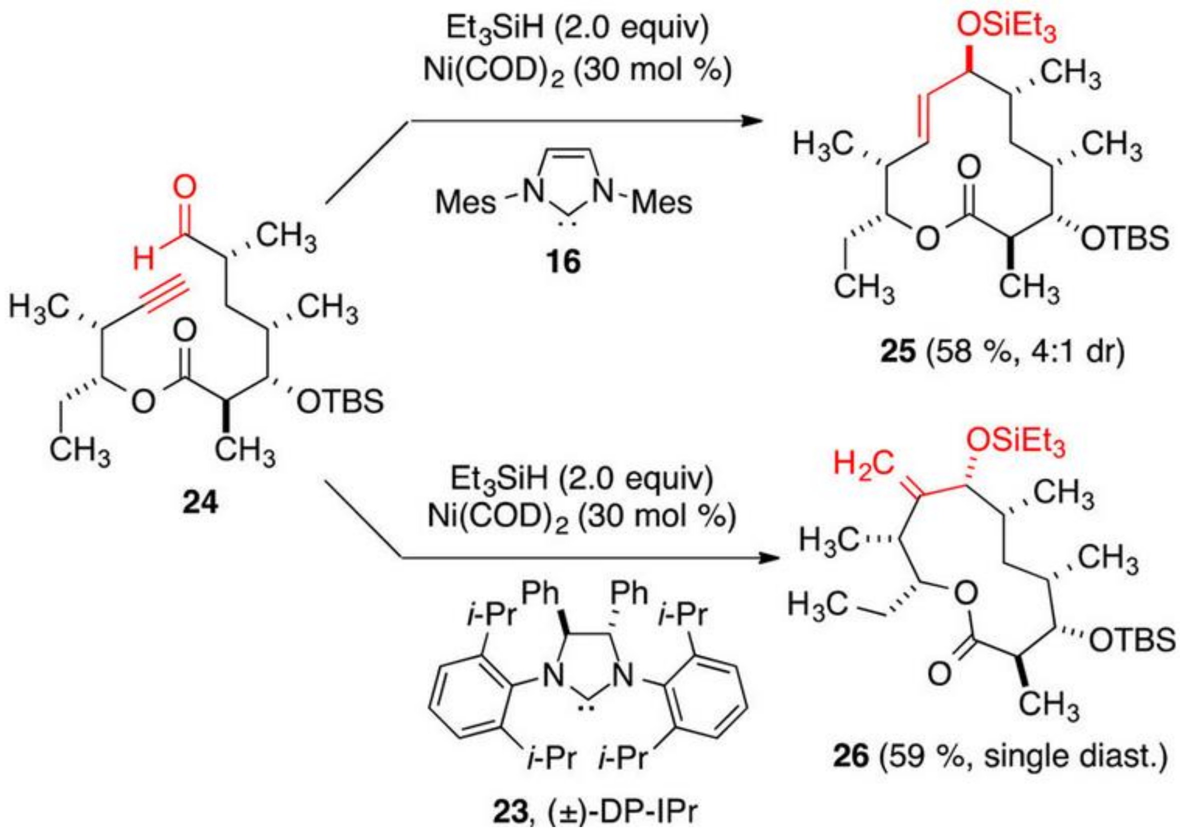
IPr (21) **sIPr (22)** **(±) DP-IPr (23)**



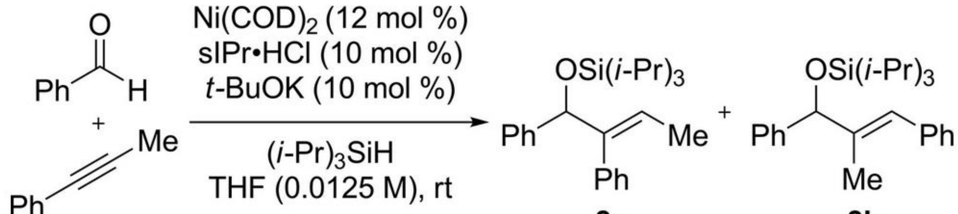
distal TS (ΔΔG‡ = 1.6 kcal/mol) proximal TS (ΔΔG‡ = 0.0 kcal/mol) affords product **27**

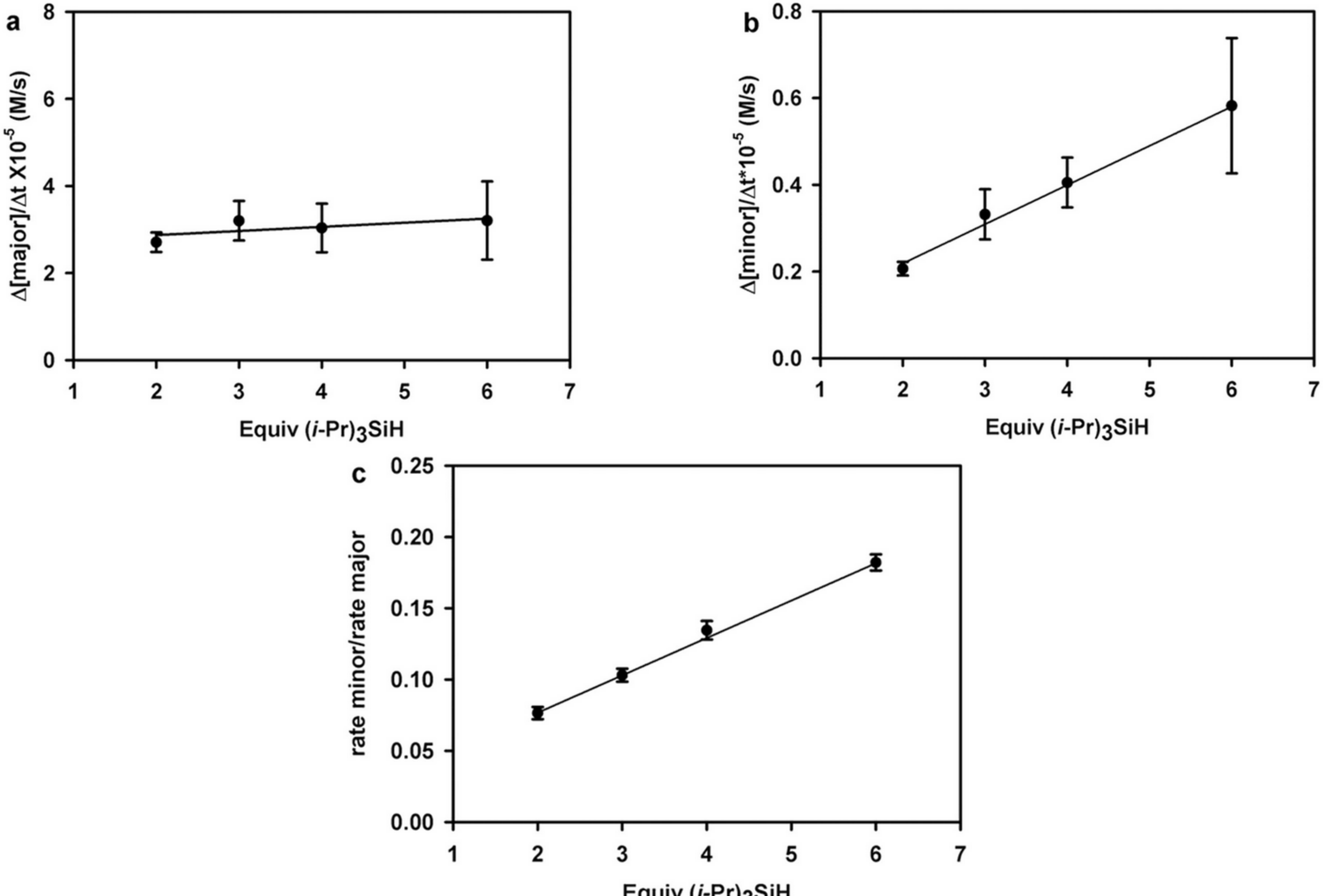
J. Montgomery, *et al. J. Am. Chem. Soc.* **2010**, *132*, 6304.

K. N. Houk and J. Montgomery, *et al. J. Am. Chem. Soc.* **2011**, *133*, 6956.

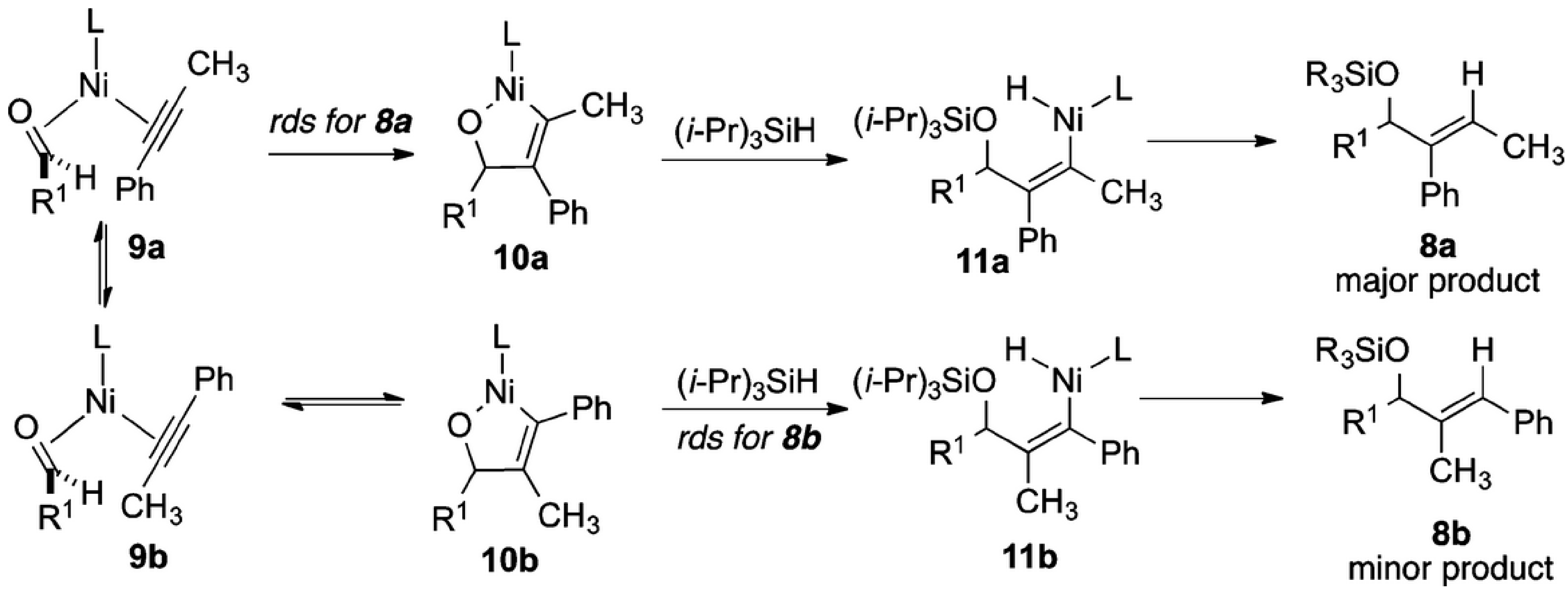

Et3SiH (2.0 equiv)
Ni(COD)2 (30 mol %)
Mes
N
N
Mes
16
OSiEt3
CH3
H3C
CH3
O
O
OTBS
CH3
CH3
25 (58 %, 4:1 dr)
O
H
CH3
H3C
CH3
O
O
OTBS
CH3
CH3
24
Et3SiH (2.0 equiv)
Ni(COD)2 (30 mol %)
Ph
Ph
i-Pr
i-Pr
N
N
i-Pr
i-Pr
23, (±)-DP-IPr
H2C
OSiEt3
CH3
H3C
CH3
H3C
O
OTBS
O
CH3
26 (59 %, single diast.)

A general strategy for regiocontrol: large ligand/large silane protocol

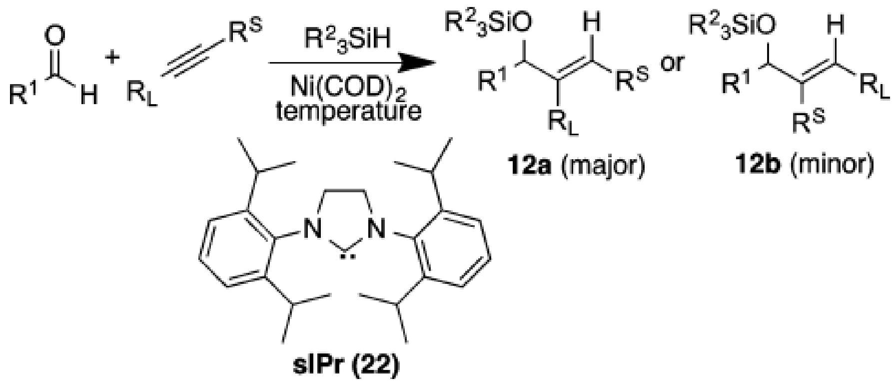




J. Montgomery, *et al. J. Am. Chem. Soc.* **2015**, *137*, 958.

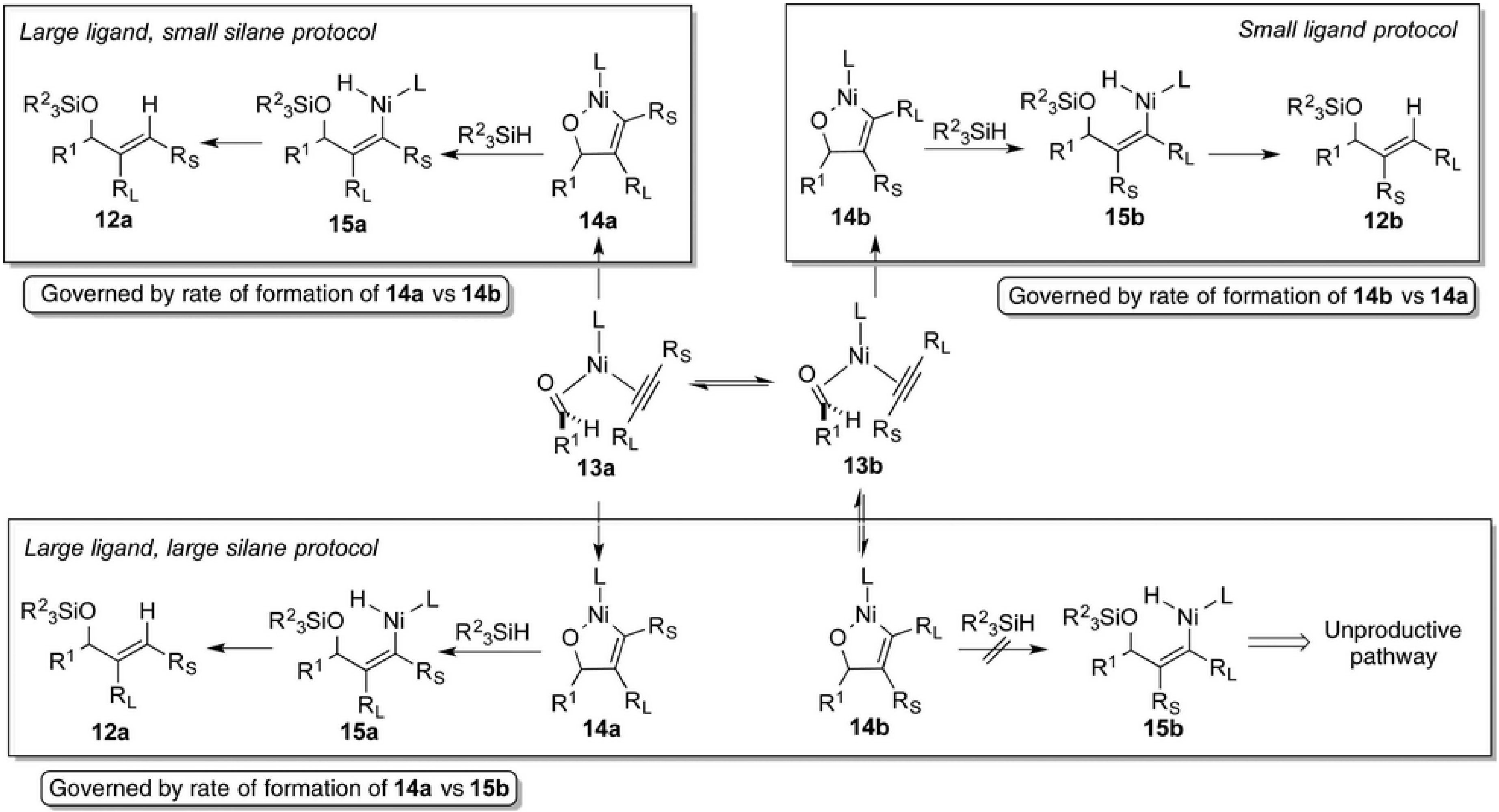


J. Montgomery, *et al. J. Am. Chem. Soc.* **2015**, *137*, 958.



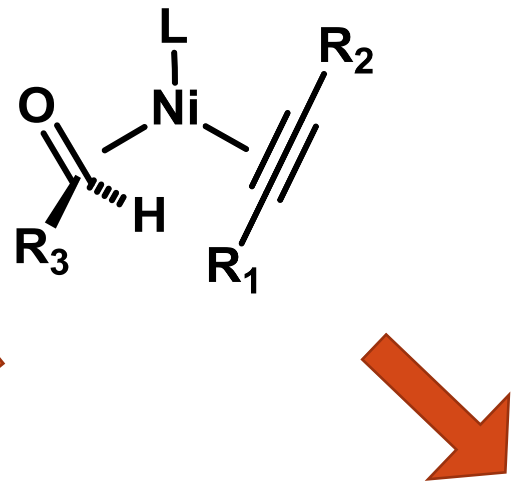
entry	R^1	R^L	R^S	R^2_3SiH	temp (°C)	% yield	**12a/12b**
1	Ph	Ph	Me	$(i\text{-Pr})_3SiH$	25	82	>98:2
2	*n*-Hept	Ph	Me	$(i\text{-Pr})_3SiH$	50	77	>98:2
3	*n*-Hept	*i*-Bu	Et	$(i\text{-Pr})_3SiH$	50	66	93:7
4	Ph	*i*-Pr	Me	$(i\text{-Pr})_3SiH$	50	78	>98:2
5	Ph	*n*-Pr	Et	$(i\text{-Pr})_3SiH$	50	56	68:32
6	*n*-Hex	*c*-hexenyl	Me	$(i\text{-Pr})_3SiH$	25	77	91:9
7	Ph	*i*-Pr	H	$(t\text{-Bu})_2MeSiH$	25	61	>98:2
8	Ph	*n*-Hex	H	$(t\text{-Bu})_2MeSiH$	25	69	95:5

J. Montgomery, *et al. J. Am. Chem. Soc.* **2015**, *137*, 958.

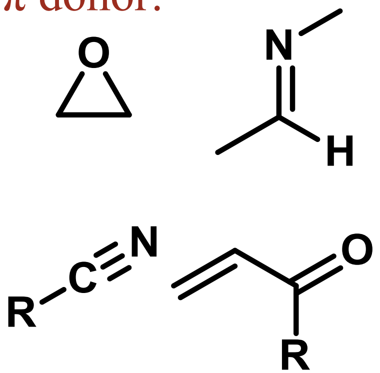


J. Montgomery, *et al. Acc. Chem. Res.*. **2015**, *48*, ASAP.

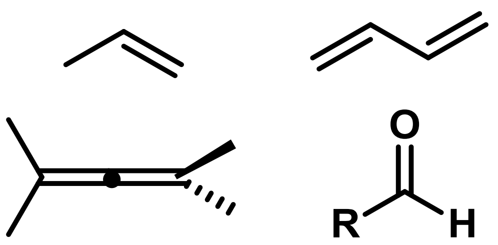
3. Reductive Coupling of Different reaction partner



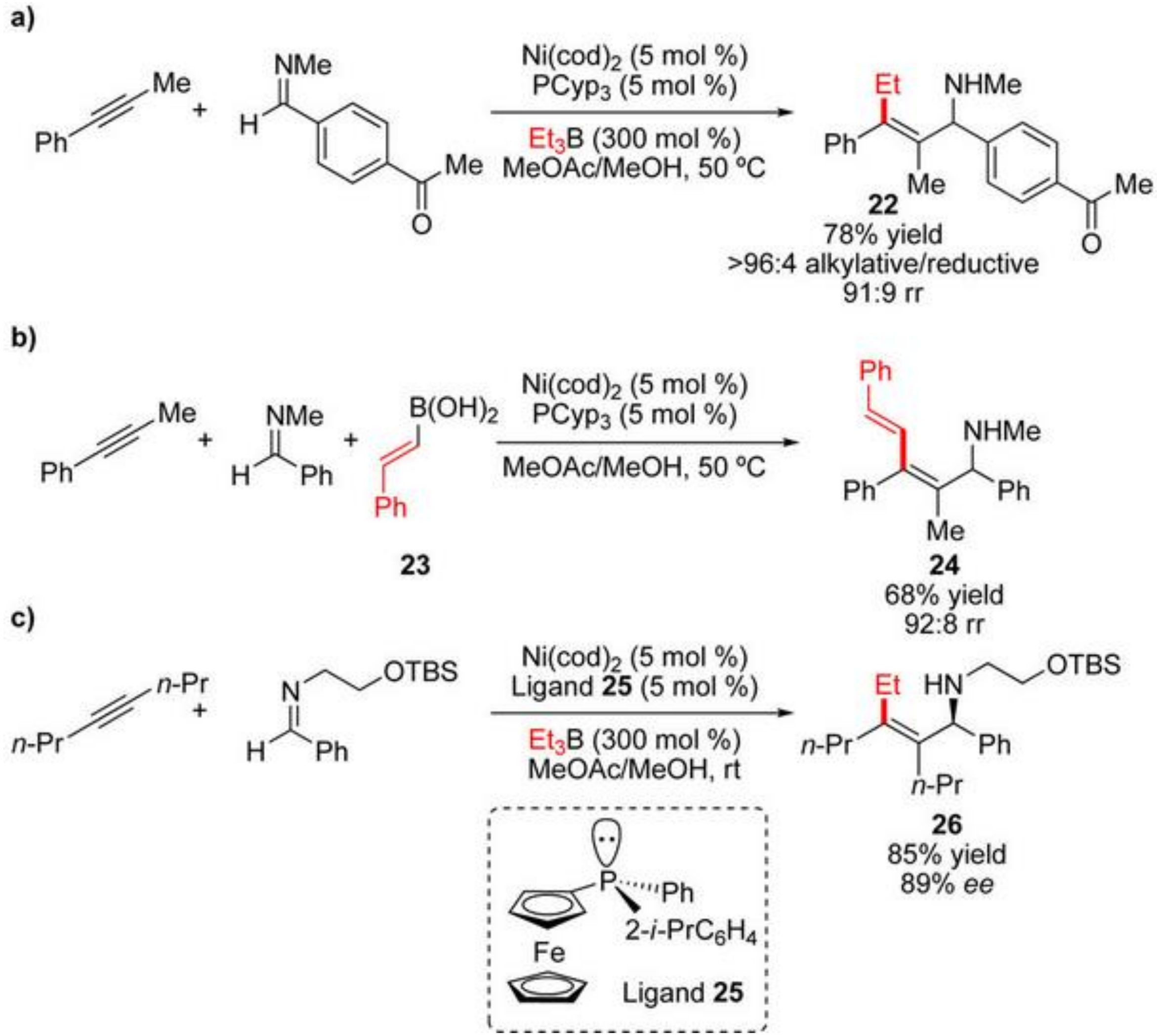
π donor:



π component:

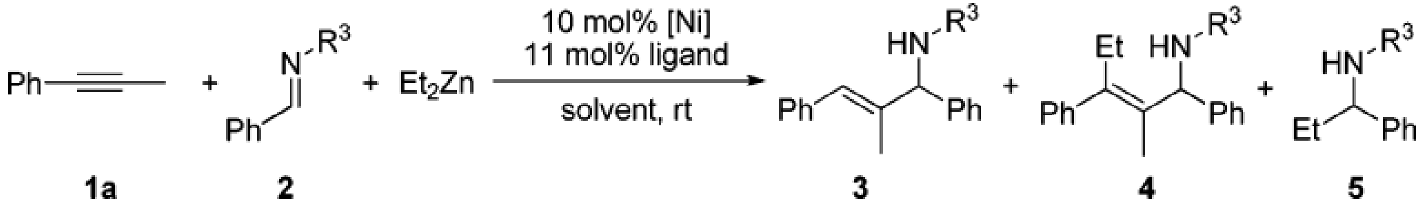


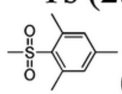
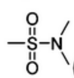
Selected examples of reductive coupling of alkyne and imines:

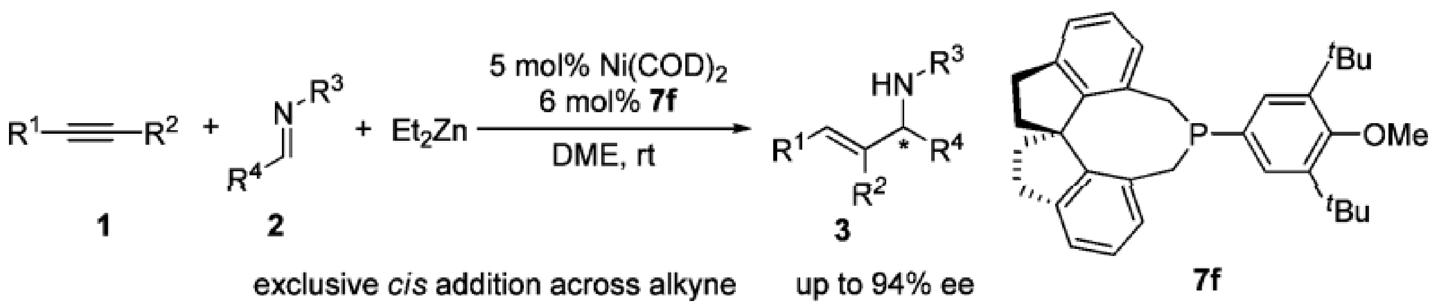


T. F. Jamison, *et al. Angew. Chem., Int. Ed.* **2003**, *42*, 1364.

T. F. Jamison, *et al. Angew. Chem., Int. Ed.* **2004**, *43*, 3941.

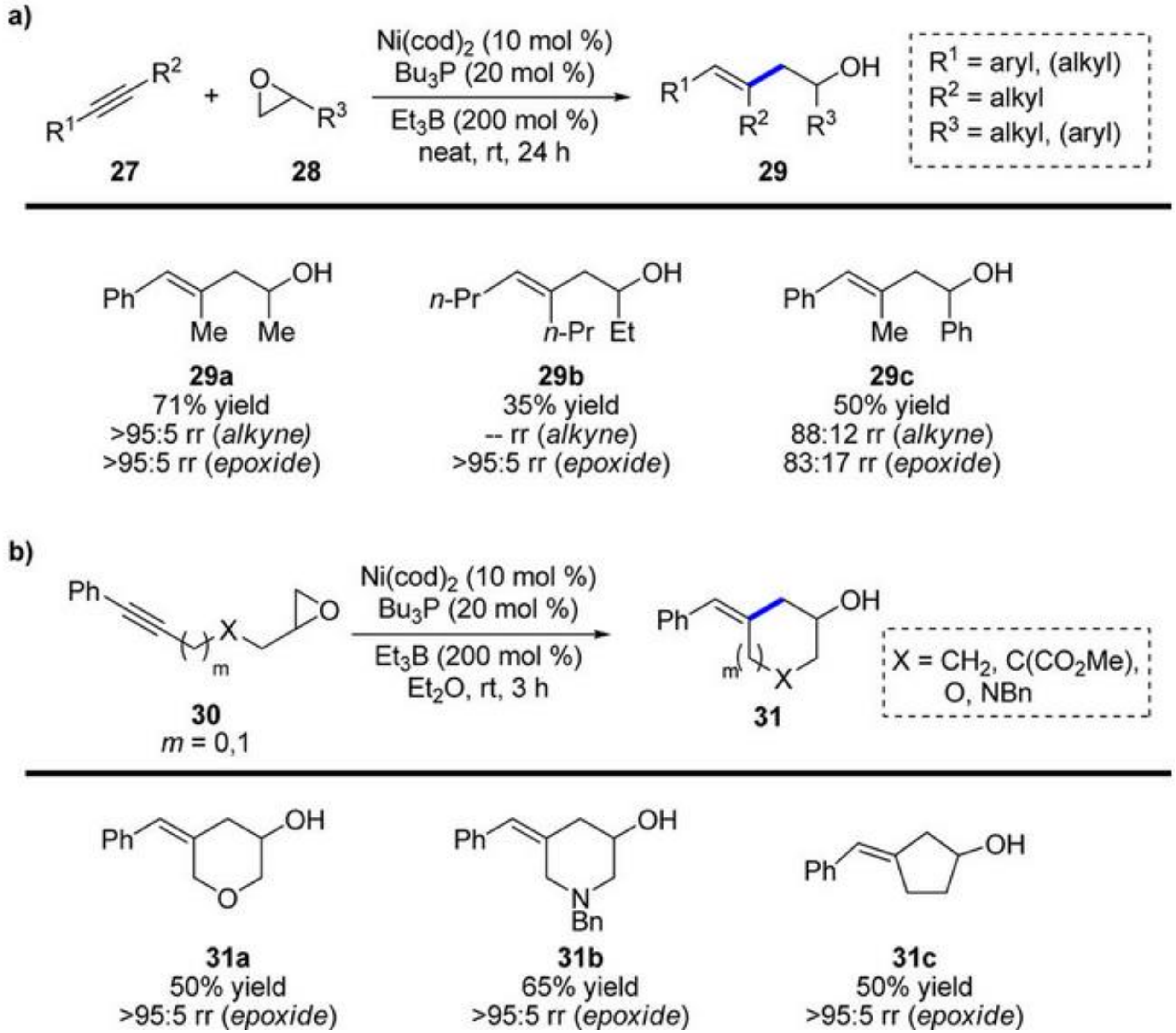


entry	R^3	[Ni]	ligand	solvent	time (h)	**3/4/5** [b]	yield of **3** (%) [c]
1	Ts (**2a**)	$Ni(acac)_2$	Ph_3P	THF	1	2:1:1	36
2	Ts (**2a**)	$Ni(acac)_2$	$(OPh)_3P$	THF	1	2:1:10	5
3	Ts (**2a**)	$Ni(acac)_2$	$(c\text{-}C_6H_{11})_3P$	THF	1	5:1:0.3	48
4	Ts (**2a**)	$Ni(acac)_2$	*n*-Bu_3P	THF	1	23:1:3	66
5	Ts (**2a**)	$Ni(acac)_2$	dppe [d]	THF	8	1:1:1	15
6	Ts (**2a**)	$Ni(COD)_2$	*n*-Bu_3P	THF	1	24:1:3	86
7 [e]	Ts (**2a**)	$Ni(COD)_2$	*n*-Bu_3P	DME	1	27:1:3	90
8 [e,f]	Ts (**2a**)	$Ni(COD)_2$	*n*-Bu_3P	DME	2	23:1:2	82
9 [e,f]	 (**2b**)	$Ni(COD)_2$	*n*-Bu_3P	DME	2	22:1:1	88
10 [e,f]	 (**2c**)	$Ni(COD)_2$	*n*-Bu_3P	DME	2	28:1:1	87



Q. L. Zhou, *et al. J. Am. Chem. Soc.* **2010**, *132*, 10955.

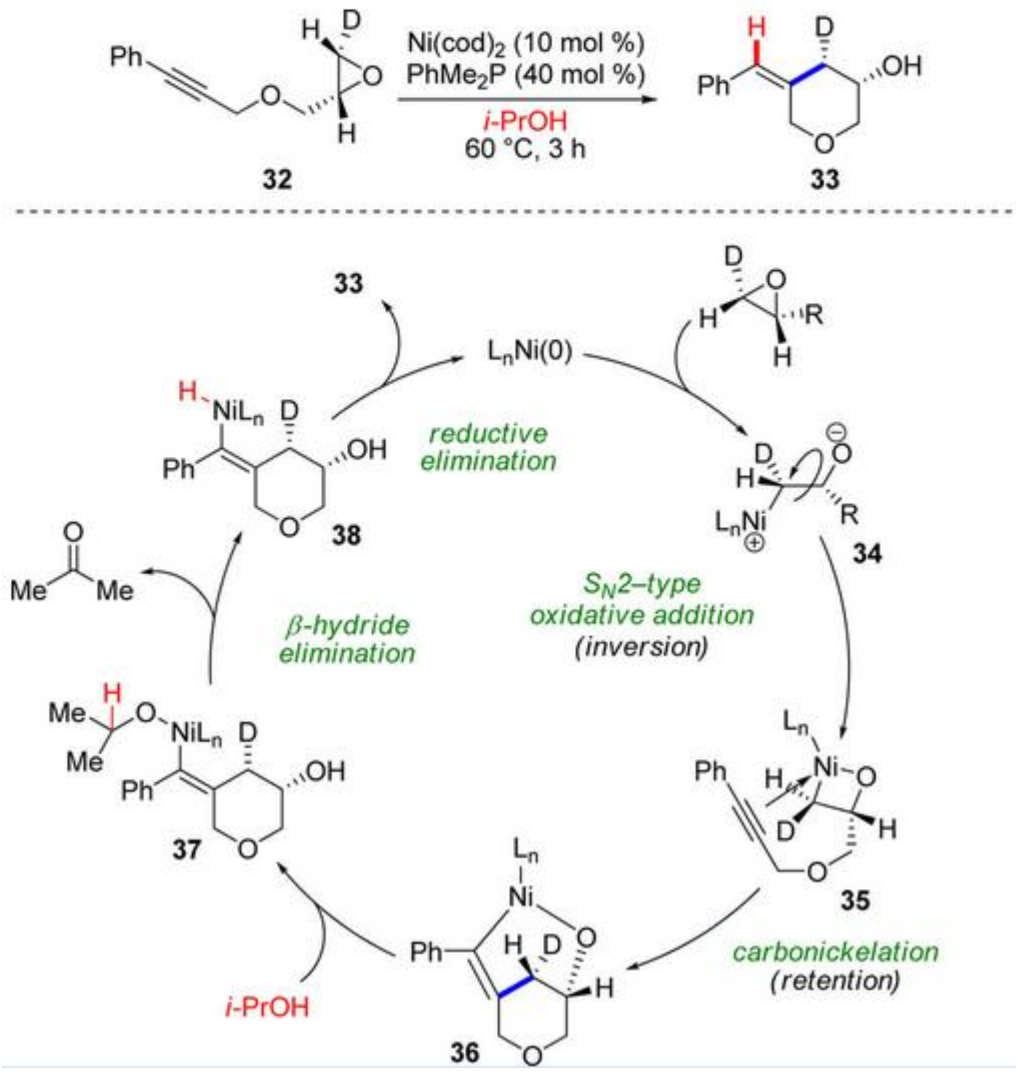
Reductive coupling of alkyne and epoxides:



T. F. Jamison, *et al.* *J. Am. Chem. Soc.* **2003**, *125*, 8076.

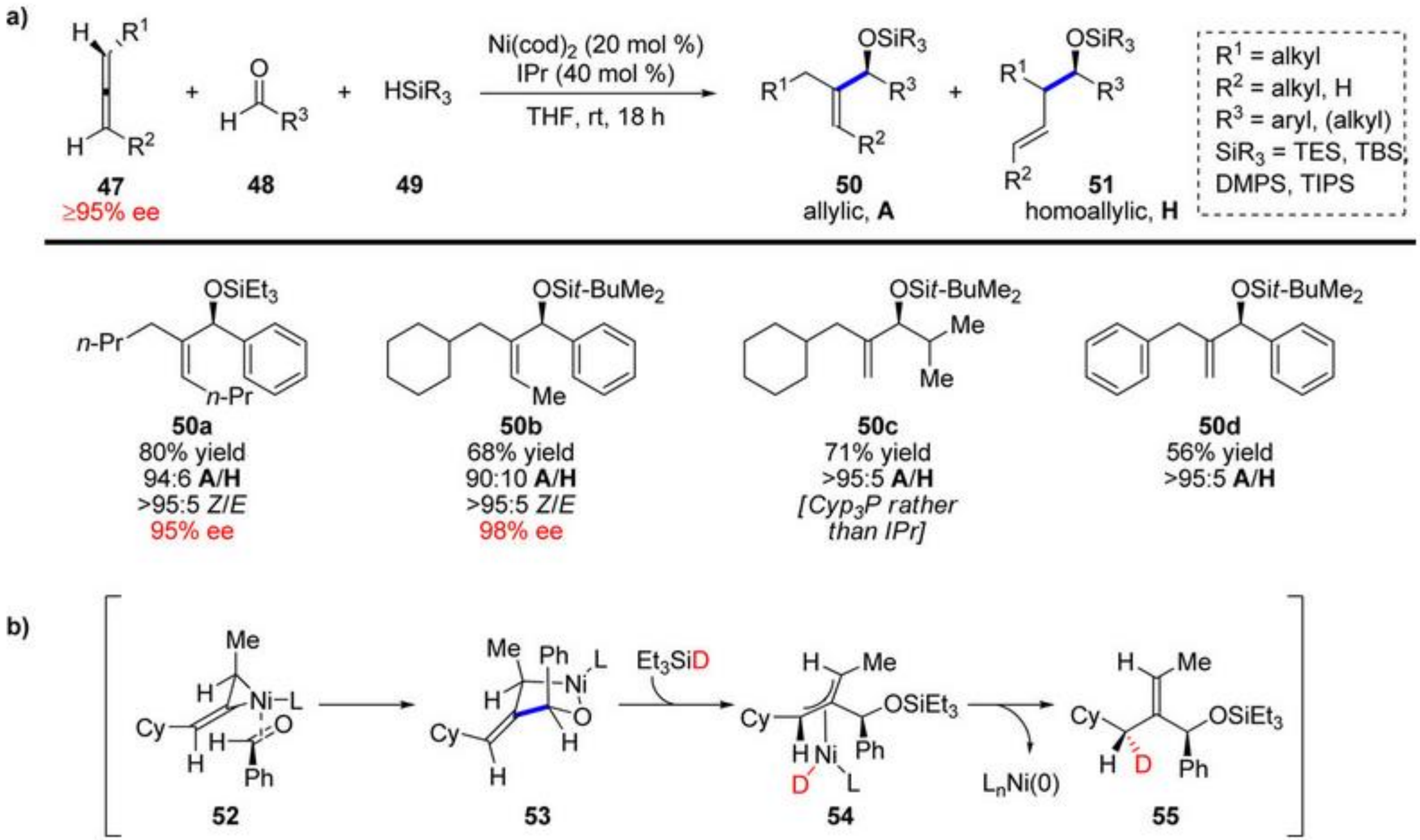
T. F. Jamison, *et al.* *Org. Lett.* **2011**, *13*, 4140.

Reductive coupling of alkyne and epoxides: mechanism study



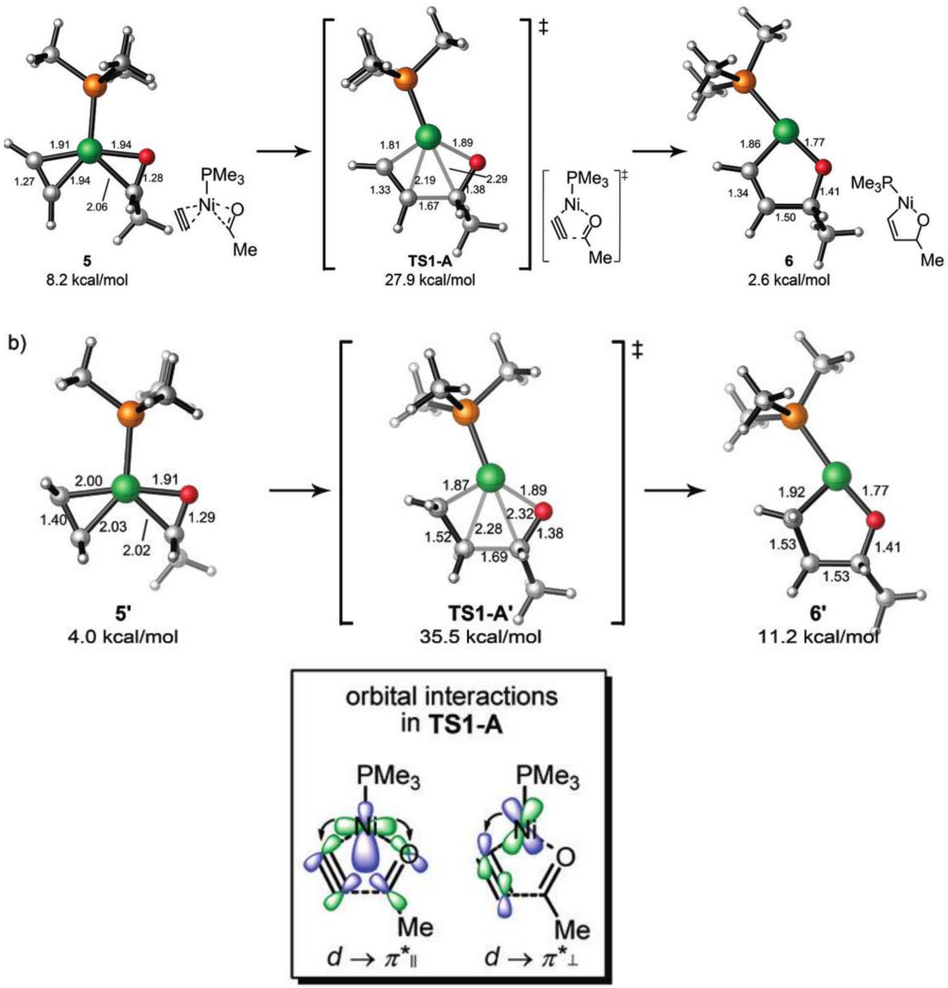
T. F. Jamison, *et al. Org. Lett.* **2011**, *13*, 4140.

Reductive coupling of allene and aldehyde:

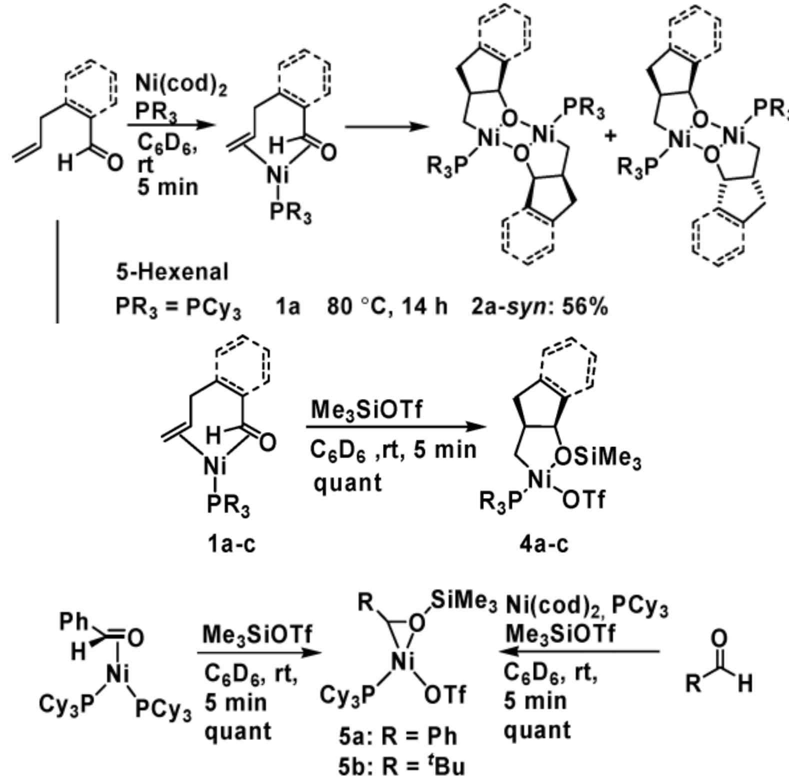


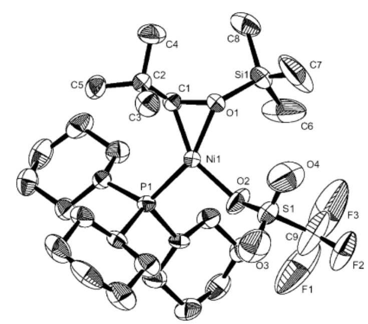
T. F. Jamison, *et al. J. Am. Chem. Soc.* **2005**, *127*, 7320.

Reductive coupling of alkene and aldehyde:



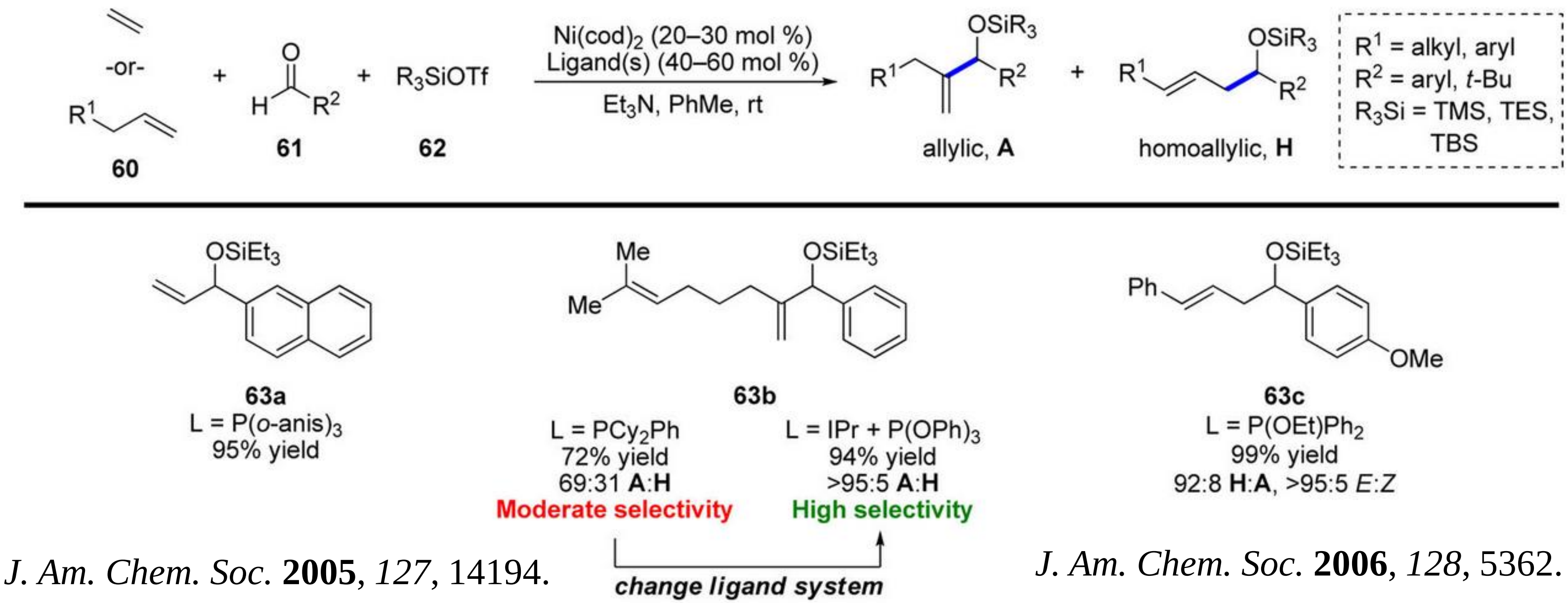
K. N. Houk and T. F. Jamison, *et al.*
J. Am. Chem. Soc. **2009**, *131*, 6654.





S. Ogoshi, *et al. J. Am. Chem. Soc.* **2004**, *126*, 11802.
S. Ogoshi, *et al. J. Am. Chem. Soc.* **2005**, *127*, 12810.

Reductive coupling of alkene and aldehyde:



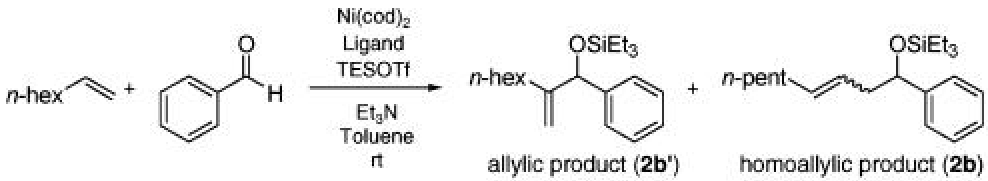
J. Am. Chem. Soc. **2005**, *127*, 14194.

J. Am. Chem. Soc. **2006**, *128*, 5362.

Angew. Chem., Int. Ed. **2007**,46, 782.

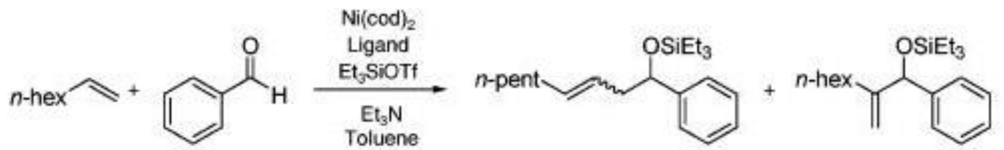
Conditions	Alkene	Ligand	Major Product
A	ethylene	P(o-anis)$_3$	n/a
B	terminal alkene	PCy_2Ph	**A**
C	terminal alkene	PPh_3 or $P(OEt)Ph_2$	**H**
D	terminal alkene	IPr and P(OPh)$_3$	**A**

Reductive coupling of alkene and aldehyde: ligand effects



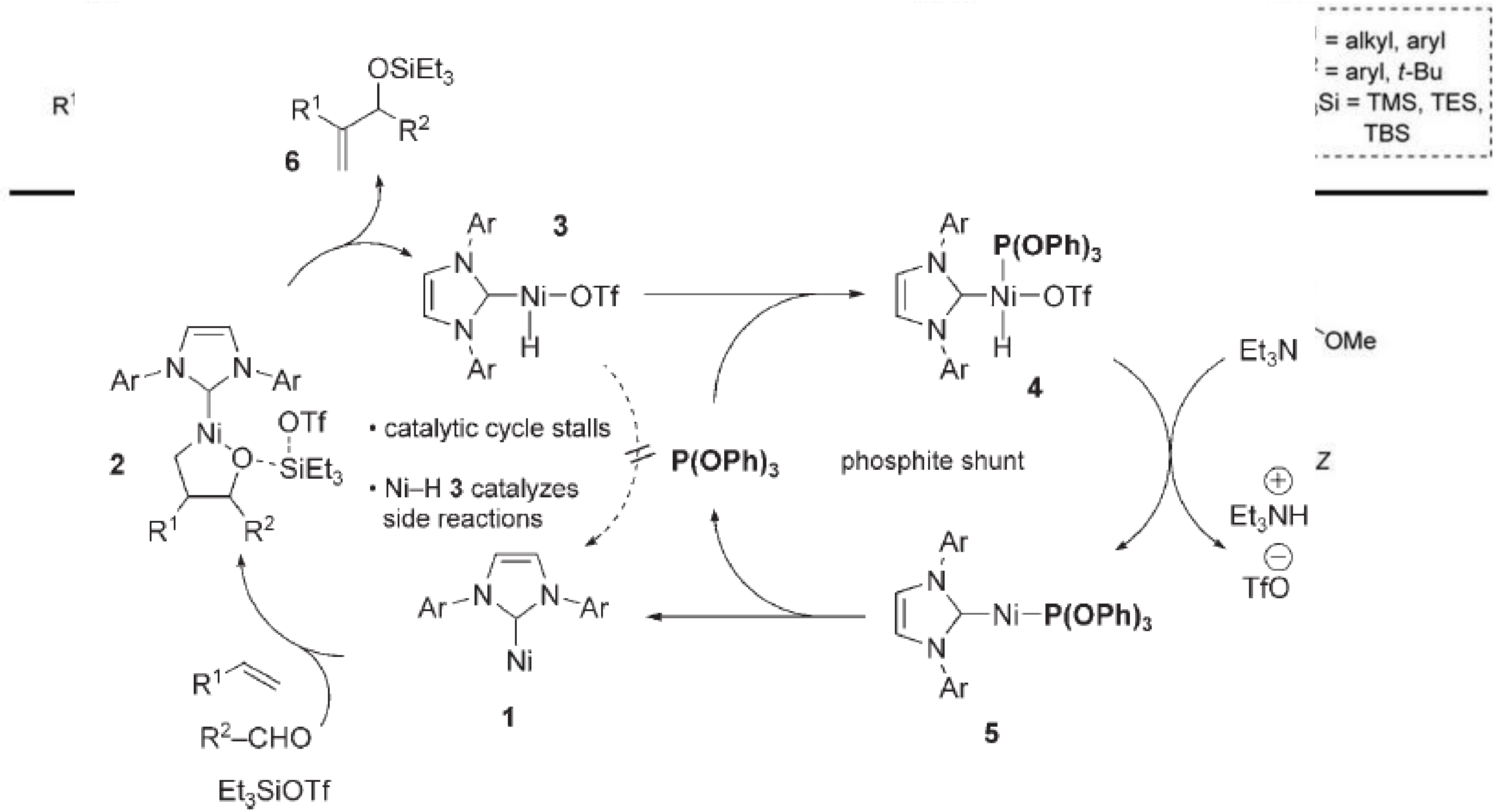
entry	ligand	cone angle [b]	ν_{CO} [b]	yield (2b') [c]	yield (2b) [c]	ratio (2b':2b) [d]	combined yield (2b'+2b)
1	$(n\text{-Bu})_3P$	132	1915	11%	27%	29:71	38%
2	$(n\text{-Oct})_3P$	107		7%	14%	23:77	21%
3	$(i\text{-Pr})_3P$	160	1915	11%	2%	85:15	13%
4	Cyp_3P			10%	3%	78:22	13%
5	Cy_3P	170	1915	13%	3%	81:19	16%
6	$(t\text{-Bu})_3P$	182		7%	2%	78:22	9%
7	Cy_2PhP	162	1917	37%	16%	70:30	53%
8 [e]	$Cy_2(o\text{-tol})P$	181		30%	5%	86:14	35%
9	$Cy_2(o\text{-Ph-Ph})P$			32%	22%	60:40	54%
10 [f]	Cy_2FcP			14%	2%	88:12	16%

T. F. Jamison, *J. Am. Chem. Soc.* **2006**, *128*, 11513.



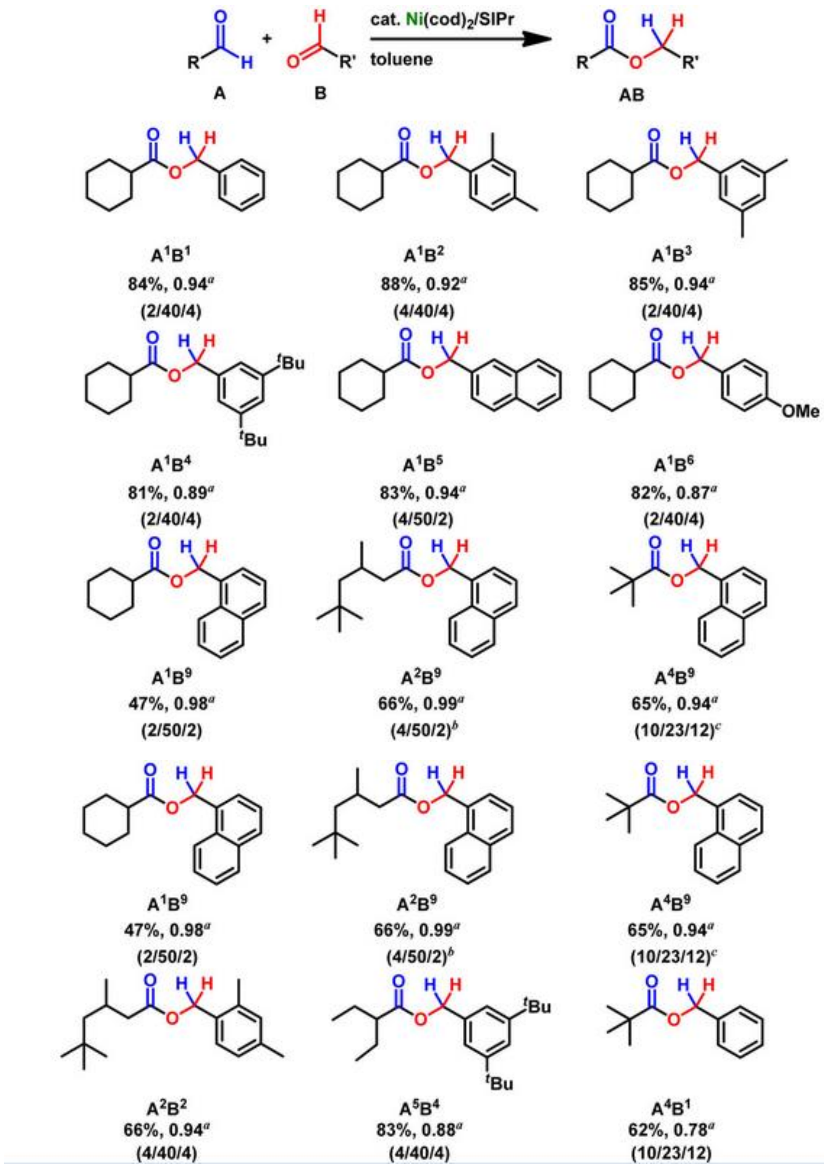
entry	ligand	cone angle [b]	ν_{CO} [b]	combined yield [c] (**2b**+**2b'**)	ratio (**2b**:**2b'**) [d]	*E*:*Z* (**2b**) [d]
1 [e]	Cy_2PhP	162	1917	73	29:71	n.d.
2	$CyPh_2P$	153	1917	84	75:25	91:9
3	(*o*-anisyl)$_3$P	194	1919	70	83:17	80:20
4	$FcPh_2P$	173		70	88:12	81:19
5	(*p*-tol)$_3$P	145	1920	78	92:8	67:33
6	Ph_3P	145	1922	73	92:8	67:33
7	(*p*-F-Ph)$_3$P	145	1924	74	92:8	57:43
8	(EtO)Ph_2P	133	1926	81	95:5	75:25
9	(*p*-CF_3-Ph)$_3$P	145	1929	44	>95:5	69:31
10	(EtO)$_2$PhP	121	1932	20	>95:5	89:11
11	(PhO)$_3$P	128	1951	<5	n.d	n.d.

T. F. Jamison, *J. Am. Chem. Soc.* **2006**, *128*, 11513.



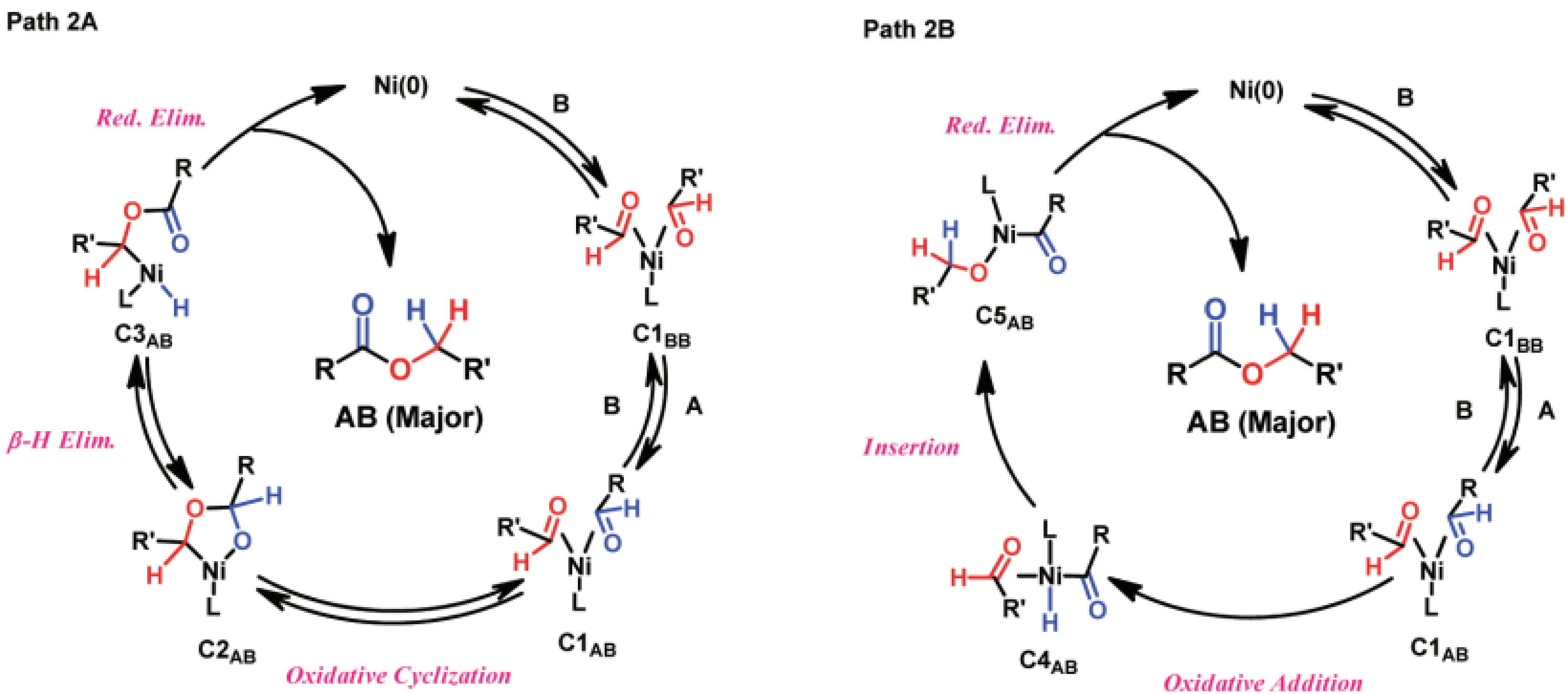
T. F. Jamison, *Angew. Chem., Int. Ed.* **2007**,46, 782.

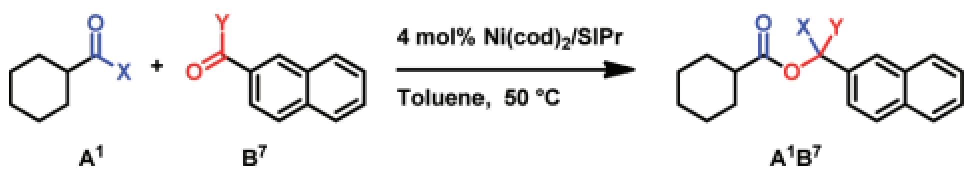
Crossed Tishchenko reaction:



S. Ogoshi, *et al. J. Am. Chem. Soc.* **2011**, *133*, 4668.

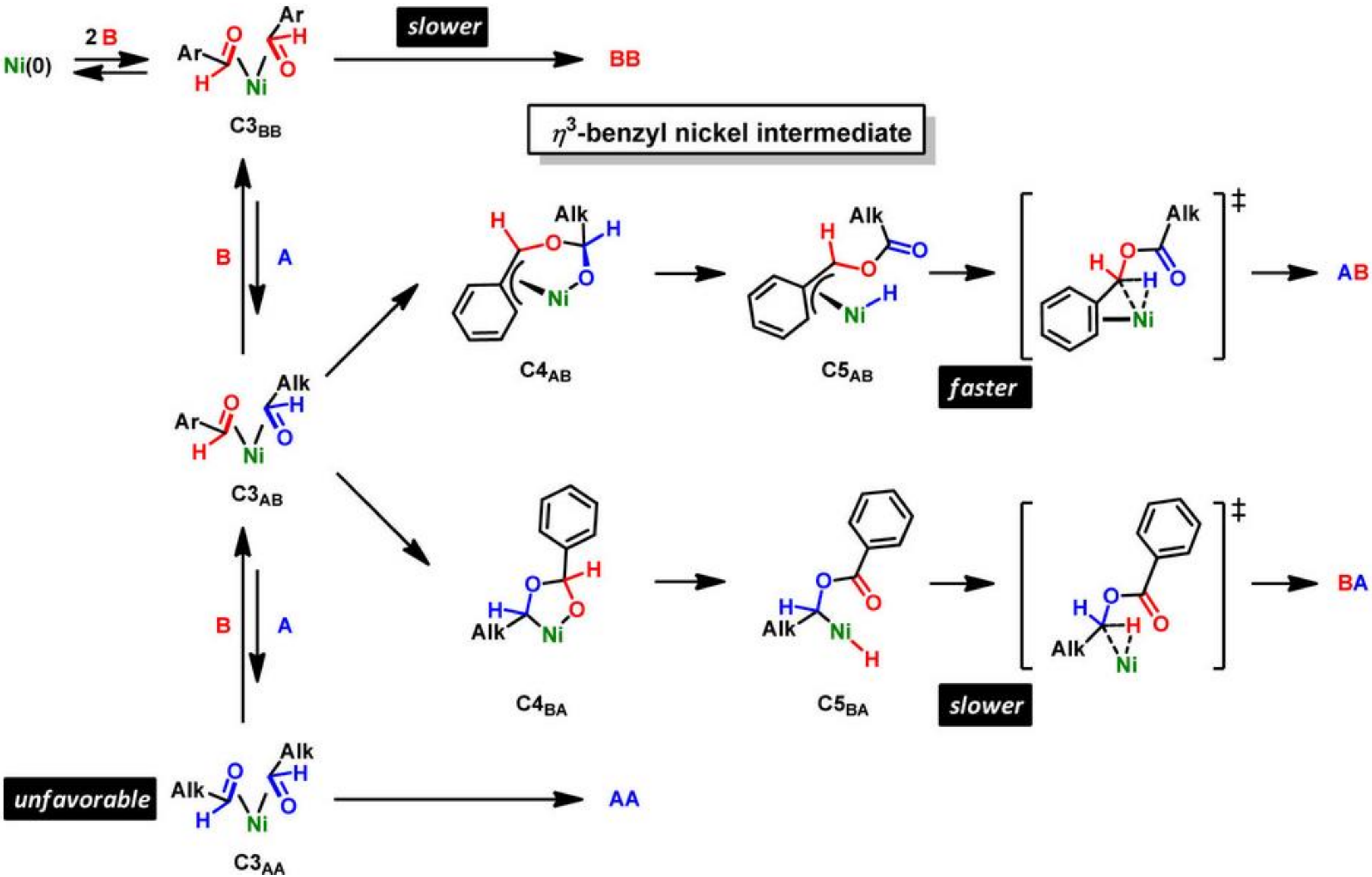
Crossed Tishchenko reaction: mechanism study





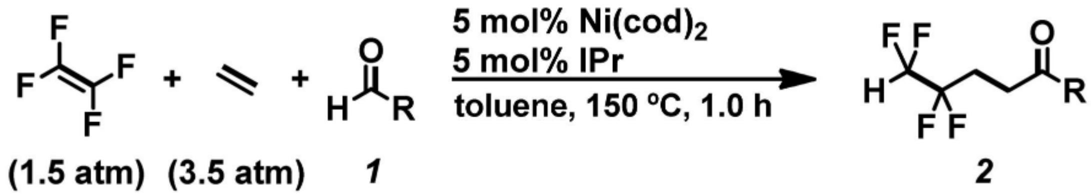
Experiment	X	Y	k_N[a]	KIE(N)[b]	Selectivity
I	H	H	12.9(1)	–	0.94
II	H	D	10.9(1)	1.2	0.93
III	D	H	6.4(3)	2.0	0.83[c]
IV	D	D	6.7(1)	1.9	0.85[d]

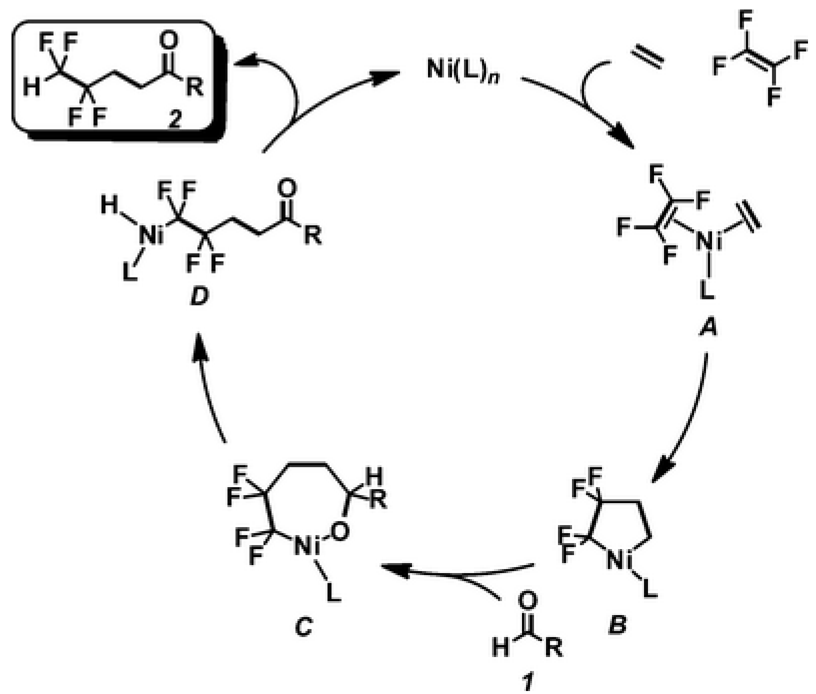
S. Ogoshi, *et al. J. Am. Chem. Soc.* **2011**, *133*, 4668.



S. Ogoshi, *et al. J. Am. Chem. Soc.* **2011**, *133*, 4668.

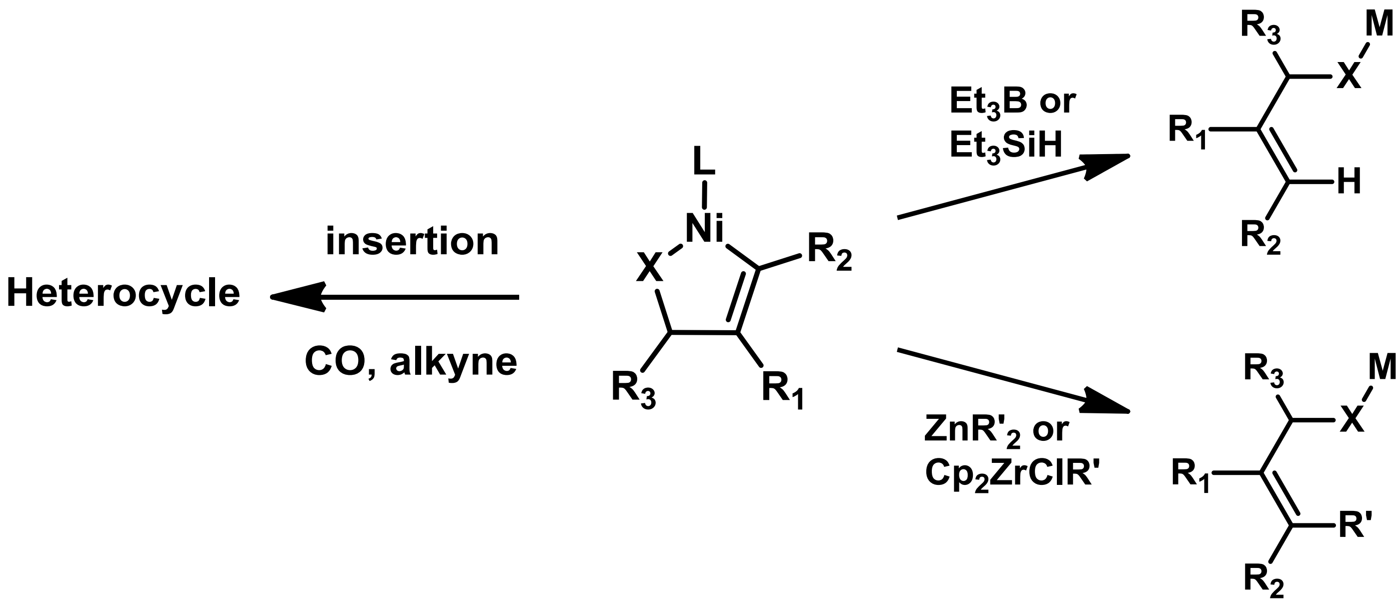
Cross-trimerization reaction of tetrafluoroethylene, ethylene, and aldehydes:



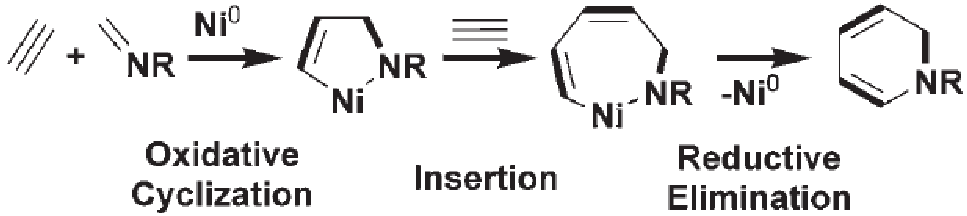


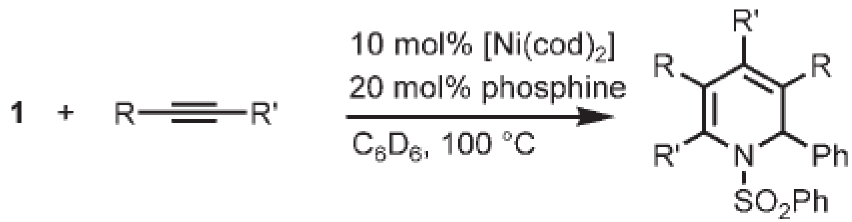
S. Ogoshi, *et al. J. Am. Chem. Soc.* **2015**, *137*, ASAP.

3. Cycloaddition Reaction

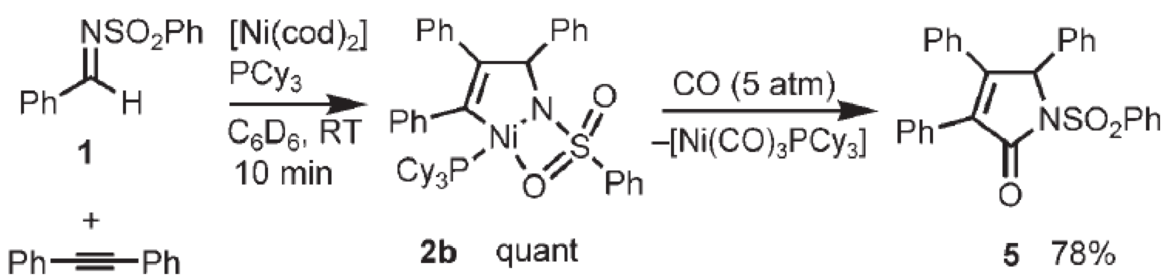


Formation of pyridine through 2+2+2:



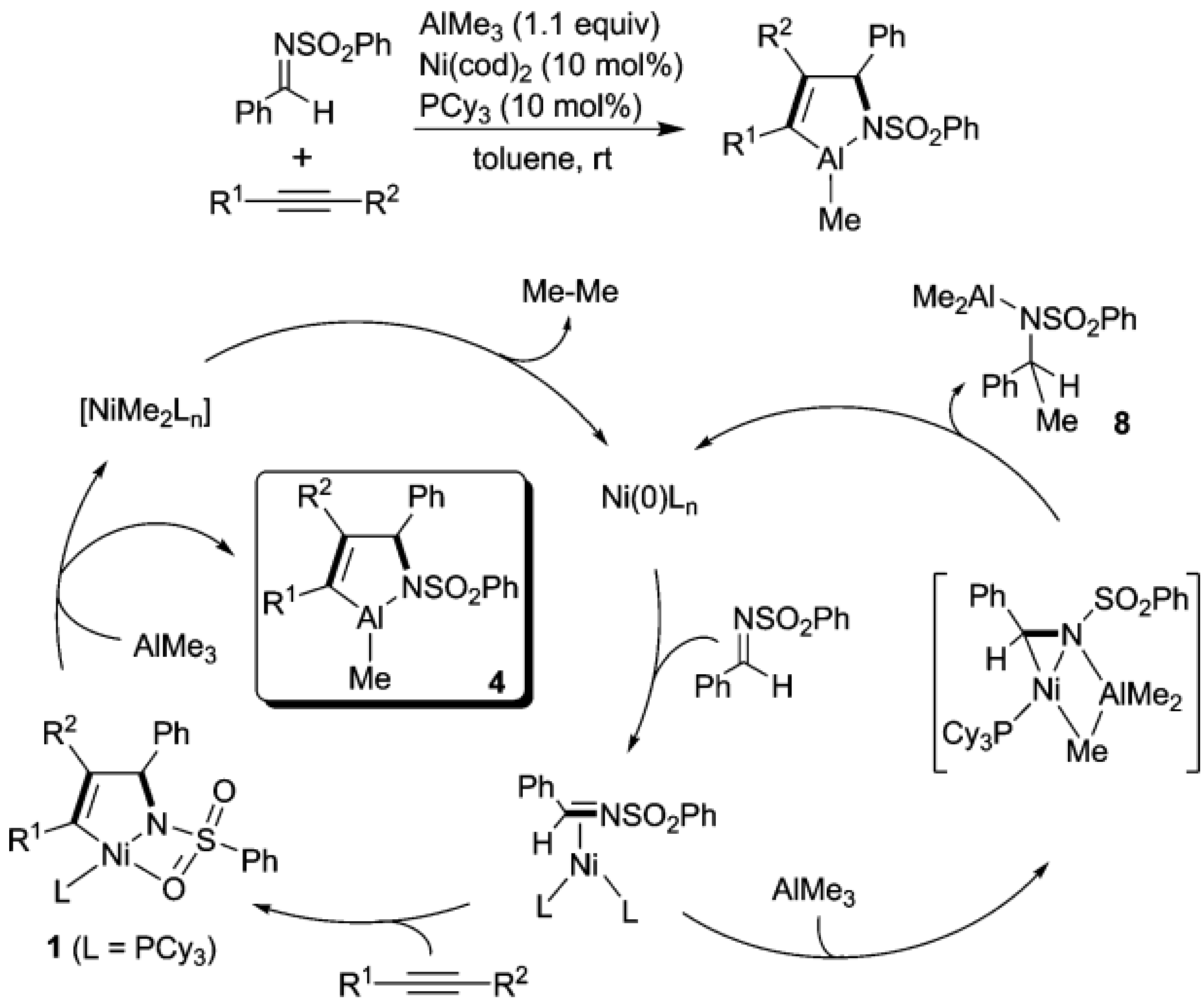


R, R' = Me	PMe*t*Bu$_2$	48 h	**6a**	87%
	PCy$_3$	24 h		64%
	P*n*Bu$_3$	24 h		17%
	P(*o*-tol)$_3$	29 h		6%
R, R' = Et	PMe*t*Bu$_2$	70 h	**6d**	64%
	PCy$_3$	24 h		26%
R = TMS, R' = H	PMe*t*Bu$_2$	18 h	**6e**	58%



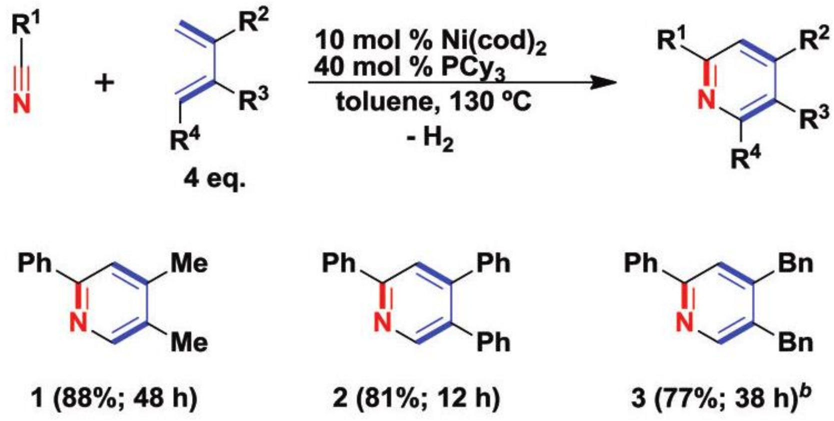
S. Ogoshi, *et al. Angew. Chem., Int. Ed.* **2007**, *46*, 4930.

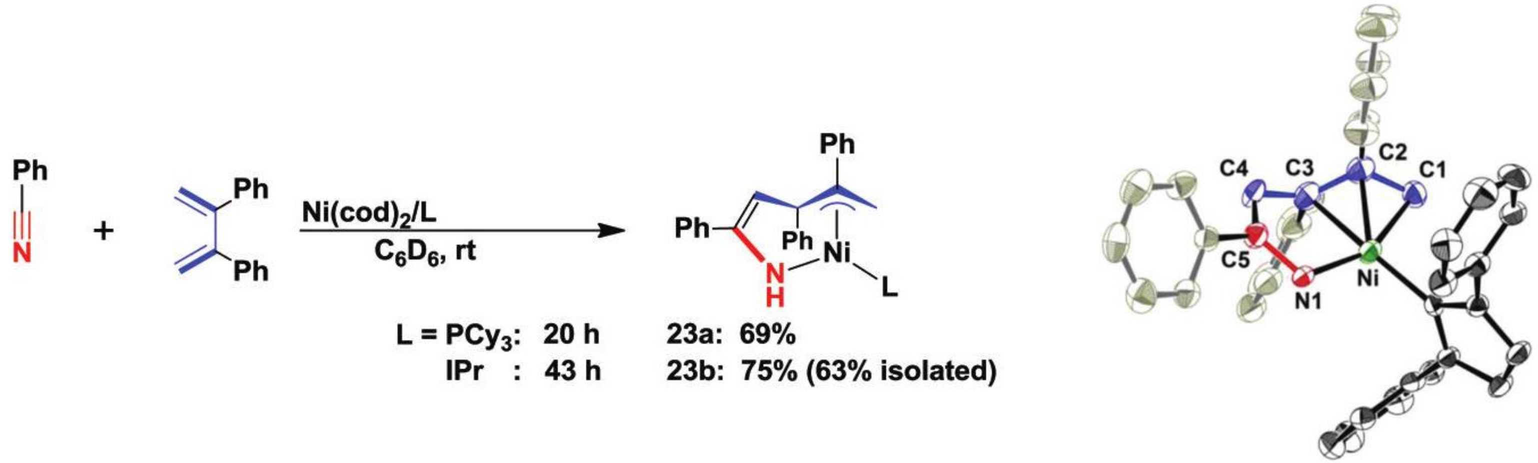
Formation of azaaluminacyclopentenes:



S. Ogoshi, *et al. J. Am. Chem. Soc.* **2009**, *131*, 9160.

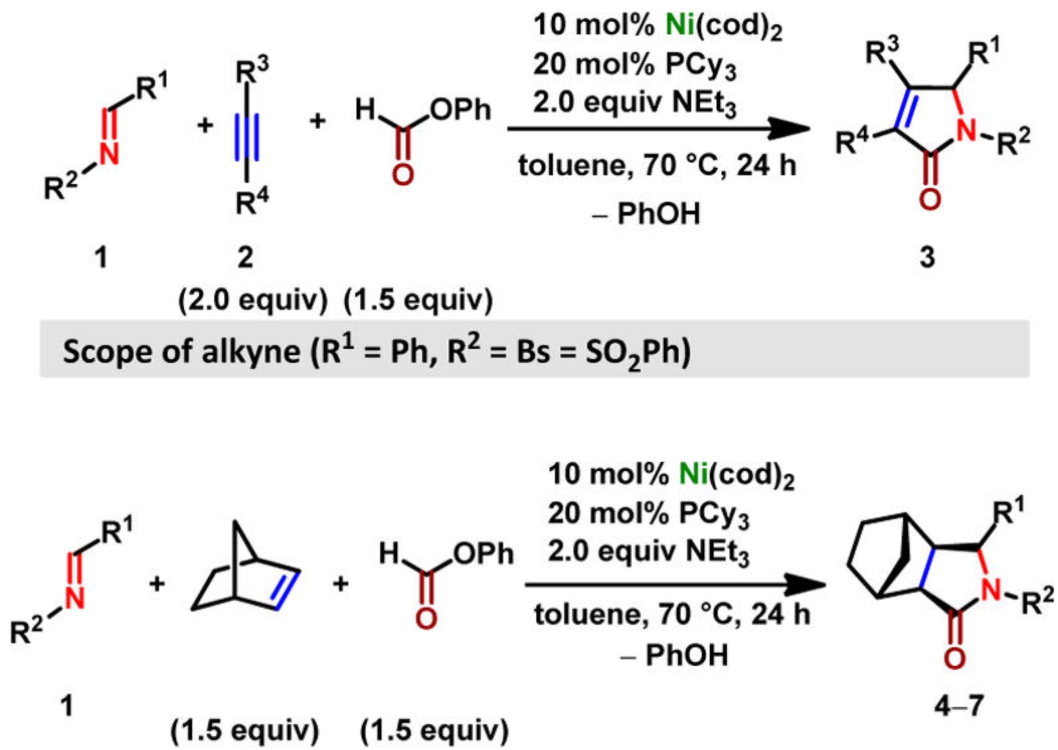
Formation of pyridine through 4+2:





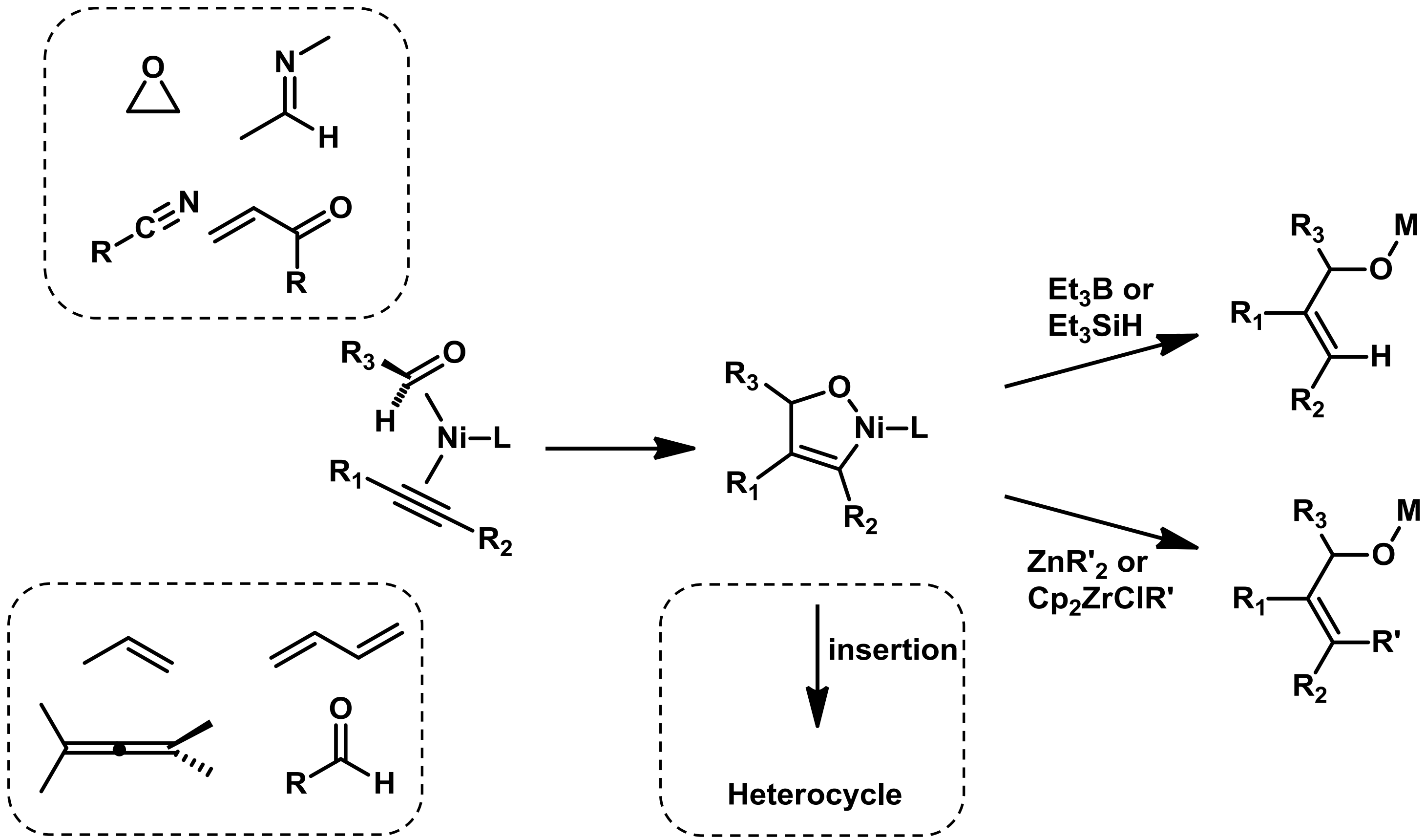
S. Ogoshi, *et al. J. Am. Chem. Soc.* **2011**, *133*, 18018.

Formation of γ-lactams through 2+2+1:



S. Ogoshi, *et al. J. Am. Chem. Soc.* **2014**, *136*, 15877.

Summary



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R2
Et3B or
Et3SiH
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M
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H
R2
ZnR'2 or
Cp2ZrClR'
R3
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R1
R'
R2
insertion
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R
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Thanks for Your Attention！