Supporting Information For:

**Amine Catalyzed Coupling of Aldehydes and Ketenes Derived
from Fischer Carbene Complexes: Formation of β -Lactones and
Enol Ethers**

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General Experimental: All reagents were purified prior to use.¹ Tetrahydrofuran and ether were distilled prior to use from sodium-benzophenone ketyl. All reactions were carried out in flame dried glassware under an argon atmosphere, unless otherwise stated. Precoated silica gel plates with UV 254 nm indicator were used for all thin-layer chromatography. Visualization was accomplished with UV light or phosphomolybdic acid stain. Silica gel 60 (230-260 mesh) was used for all flash chromatography using the Still method.² All NMR spectra were obtained in CDCl₃ on either a 400 MHz (100 MHz ¹³C) or 500 MHz (125 MHz ¹³C) spectrometer; chemical shifts are reported in ppm relative to TMS (¹H δ 0.00) or the center line of CDCl₃ (¹³C δ 77.00). Multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), p (pentet), hx (hextet), hp (heptet), m (multiplet), or br (broadened). All coupling constants, *J*, are reported in Hz. All IR data are reported in cm⁻¹. Mass spectral data were obtained from a reverse geometry, extended mass range, magnetic sector mass spectrometer.

1. Armarego, W. L. F.; Perrin, D. D. *Purification of Laboratory Chemicals*; Butterworth-Heinemann: Oxford, 1996.

2. Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

4-Methyl-3-methoxy-3-phenyloxetan-2-one 3b, 3b'.

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (1.0 g, 3.2 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (35 mL). To the solution was added acetaldehyde (0.70 mL, 12.8 mmol) and DMAP (47 mg, 0.34 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was irradiated with a 450 watt Hg lamp in a water cooled quartz immersion well for 20 h. The crude reaction mixture was then concentrated and chromatographed on silica gel (99:1 hexanes: EtOAc) to yield 305 mg (55%) of 4-methyl-3-methoxy-3-phenyloxetan-2-one as a colorless oil in a 9:1 mixture of diastereomers as evidenced by methoxy signals at 3.36 ppm and 3.33 ppm. ¹H NMR (500 MHz): major diastereomer δ 7.45-7.35 (m, 5H), 4.88 (q, 1H, *J* = 6.4 Hz), 3.36 (s, 3H), 1.04 (d, 3H *J* = 6.4 Hz). Minor diastereomer: δ 7.45-7.35 (m, 5H), 4.63 (q, 1H, *J* = 6.3 Hz), 3.33 (s, 3H). ¹³C NMR (125 MHz): major diastereomer δ 168.7, 131.6, 129.4, 128.8, 127.3, 94.7, 81.1, 53.9, 16.6. IR (neat, mixture) 3063, 2982, 2833, 1819, 1450, 1269, 1151, 1026, 837, 702 cm⁻¹. MS (mixture, CI): 148 (M⁺, 100), 133 (25), 121 (19), 117 (21), 105 (77). HRMS (CI) mass calcd for C₁₀H₁₂O (M-44)⁺: 148.0888; found: 148.0889.

4-Propyl-3-methoxy-3-phenyloxetan-2-one 3c.

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (1.0 g, 3.1 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (25 mL). To the solution was added n-butyraldehyde (1.1 mL, 12.5 mmol) and DMAP (48 mg, 0.34 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was irradiated with a 450 watt medium pressure Hg lamp in a water cooled quartz immersion well for 14 h. The crude reaction mixture was then concentrated and chromatographed on silica gel (95:5 hexanes: EtOAc) to yield 293 mg (43%) of 4-propyl-3-methoxy-3-phenyloxetan-2-one as a colorless oil as a 23:1 mixture of diastereomers as evidenced by methane resonances at 4.70 ppm and 4.45 ppm in the ^1H NMR spectrum. Spectral data for major isomer: ^1H NMR: (500 MHz) δ 7.45-7.35 (m, 5H), 4.70 (dd, 1H, $J = 9.8, 4.1$ Hz), 3.41 (s, 3H), 1.40-1.36 (m, 1H), 1.28-1.20 (m, 2H), 1.20-1.11 (m, 1H), 0.80 (t, 3H, $J = 7.2$ Hz). ^{13}C NMR: (125 MHz) δ 168.9, 131.4, 129.4, 128.6, 127.3, 94.5, 84.7, 53.9, 32.9, 18.2, 13.4. IR (neat) 2962, 1820, 1450, 1272, 1134, 1071, 902, 829 cm^{-1} . MS (EI): 176.1 ($\text{M}-\text{CO}_2$) $^+$: 147.1 (100), 133.1 (8), 121.1 (20), 115.1 (21), 105.0 (75). HRMS: mass calcd for $\text{C}_{12}\text{H}_{16}\text{O}$ ($\text{M}-\text{CO}_2$) $^+$: 176.1201; found: 176.1201.

4-Isopropyl-3-methoxy-3-phenyloxetan-2-one **3d, 3d'**.

Pentacarbonyl-[(methoxy)(phenyl)methylene]chromium(0) (1.0 g, 3.2 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (35 mL). To the solution was added *iso*-butyraldehyde (1.10 mL, 12.8 mmol) and DMAP (47 mg, 0.34 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was then irradiated with a 450 watt Hg lamp in a water cooled quartz immersion well for 20 h. The crude reaction mixture was then concentrated and chromatographed on silica gel (99:1 hexanes: EtOAc) to yield 238 mg (35%) of 4-isopropyl-3-methoxy-3-phenyloxetan-2-one as a colorless oil in a 3.3:1:1.6 mixture of inseparable diastereomers and ketene dimer. ¹H NMR (500 MHz): major diastereomer: δ 7.45-7.38 (m, 5H), 4.27 (d, 1H, J = 10.4 Hz), 3.45 (s, 3H), 1.42 (d sep, 1H, J = 10.6, 6.6 Hz), 0.92 (d, 3H, J = 6.5 Hz), 0.59 (d, 3H, J = 6.6 Hz). ¹H NMR (500 MHz): minor diastereomer δ 7.45-7.38 (m, 5H), 4.03 (d, 1H, J = 10.1 Hz), 3.37 (s, 3H), 2.34 (m, 1H), 1.07 (d, 3H, J = 6.7 Hz), 1.05 (d, 3H, J = 6.7 Hz). ¹³C NMR (125 MHz): major diastereomer δ 168.9, 131.1, 129.3, 128.5, 127.4, 94.3, 89.7, 54.0, 28.2, 18.2, 17.0. IR mixture (neat) 3063, 2965, 1822, 1450, 1270, 1139, 1053, 964, 884, 705 cm⁻¹. MS (mixture, EI): 282.1 (11), 269.1 (20), 268.1 (76), 225.1 (37), 176.1 (M⁺, 18), 161.1 (28), 129.1 (9), 121.1 (13). HRMS: mass calcd for C₁₃H₁₆O (M-CO₂)⁺: 176.1201; found: 176.1201.

3-Methoxy-3,4-diphenyloxetan-2-one **3e, 3e'**.

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (1.25 g, 4.10 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (35 mL). To the solution was added benzaldehyde (1.63 mL, 16.0 mmol) and DMAP (60 mg, 0.5 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and pressurized (30 psi). The tube was then irradiated with a 450 watt Hg lamp in a water cooled quartz immersion well for 20 h. The crude reaction mixture was then concentrated and chromatographed on silica gel

(99:1 hexanes: EtOAc) to yield 341mg (33%) of 3-methoxy-3,4-diphenyloxetan-2-one as a colorless oil in a 15:1 mixture of diastereomers as evidenced by methoxy signals at 3.43 ppm and 3.19 ppm. ^1H NMR (500 MHz): major diastereomer δ 7.18-7.12 (m, 10H), 5.76 (s, 1H), 3.43 (s, 3H), ^{13}C NMR (125 MHz): major diastereomer δ 168.9, 133.5, 131.1, 129.1, 128.5, 128.3, 128.0, 127.6, 126.2, 97.09, 84.9, 54.2. IR (neat) 3063, 2941, 2835, 1828, 1450, 1259, 1126, 900, 696 cm^{-1} . MS (EI): 210.1 ($\text{M}-\text{CO}_2^+$, 13), 191.1 (21), 172.1 (10), 148.1 (37), 121.1 (18), 105 (100). HRMS (EI): mass calcd for $\text{C}_{15}\text{H}_{14}\text{O}$ ($\text{M}-44$) $^+$: 210.1044; found: 210.1041. ^1H NMR (500 MHz): minor diastereomer: δ 7.18-7.12 (m, 10H), 5.53 (s, 1H), 3.19 (s, 3H).

***Z* and *E* 1-Methoxy-1-phenyl-2-(*p*-methoxyphenyl)ethene 4g/g'.**

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (1.25 g, 4.10 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (35 mL). To the solution was added *p*-anisaldehyde (1.94 mL, 16.0 mmol) and DMAP (60 mg, 0.5 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was irradiated with a 450 watt Hg lamp in a water cooled quartz immersion well for 20 h. The crude reaction mixture was then concentrated and chromatographed (99:1 hexanes: EtOAc) to yield 585 mg (61%) of 1-methoxy-1-phenyl-2-(*p*-methoxyphenyl)ethene as a colorless oil in a 3:1 mixture of *Z*:*E* isomers, as evidenced by methoxy signals at 3.86 ppm, 3.66 ppm, 3.83 ppm, and 3.77 ppm, inseparable by chromatography ^1H NMR *Z* isomer: δ 7.70 (d, 2H, $J = 8.8$ Hz), 7.58 (d, 2H, $J = 8.3$ Hz), , 6.92 (m, 3H), 6.12 (s, 1H). 3.86 (s, 3H), 3.66 (s, 3H). *E* isomer δ 7.43-7.29 (m, 5 H), 6.71 (m, 2 H), 5.82 (s, 1 H), 3.83(s, 3 H), 3.77 (s, 3 H). ^{13}C NMR (mixture, 125 MHz) δ 158.2, 157.3, 156.0, 154.5, 136.5, 136.3, 129.8, 129.8, 129.2, 129.2, 128.6, 128.4, 128.3, 128.1, 127.9, 126.2, 113.8, 113.4, 112.4, 101.0, 57.5, 55.4, 55.2, 55.0. IR (mixture, neat): 2987, 2934, 2835, 1606, 1516, 1248, 1176, 1066, 1033, 773 cm^{-1} . MS (mixture, EI): 268.1 (19), 254.1 (31), 241.1 (100), 240.1 (M^+ , 50), 225.1 (91), 197.1 (62), 165.1 (47), 153.1 (33). HRMS: calcd for $\text{C}_{16}\text{H}_{16}\text{O}_2$: 240.1150; found: 240.1153.

***Z* and *E* 1-Methoxy-4-methyl-1-phenyl-1,3-pentadiene 4h/h'.**

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (500 mg, 1.6 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (20 mL). To the solution was added 3-methyl-2-butenal (610 μ L, 6.4 mmol) and DMAP (23 mg, 0.19 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was irradiated with a 450 watt Hg lamp in a water cooled quartz immersion well for 15 h. The crude reaction mixture was concentrated and chromatographed on silica gel (99:1 hexanes: EtOAc) to yield 130 mg (43%) of 1-methoxy-4-methyl-1-phenyl-1,3-pentadiene as a colorless oil in a 1:1 mixture of *Z*:*E* isomers inseparable by chromatography ^1H NMR (500 MHz): mixture δ 7.52-7.27 (m, 10H), 6.34 (dhp, 1H, J =11.2, 1.3 Hz), 6.16 (d, 1H, J =11.2 Hz), 5.89 (dhp, 1H, J =10.9 Hz, J = 1.3 Hz), 5.69 (d, 1H, J =10.9 Hz). 3.74 (s, 3H), 3.62 (s, 3H), 1.89 (s, 3H), 1.82 (s, 3H), 1.79 (s, 3H), 1.74 (s, 3H). ^{13}C NMR (125 MHz, mixture) δ 156.0, 153.6, 136.2, 136.0, 135.4, 130.8, 129.1, 128.4, 128.2, 128.0, 127.7, 125.8, 120.5, 119.2, 110.8, 98.9, 59.2, 55.3, 26.4, 26.2, 18.6, 18.3. IR (neat, mixture): 3053, 2907, 1595, 1448, 1228, 1115, 1068, 760 cm^{-1} . MS (EI, mixture): 188.1 (M^+ , 100), 173.1 (27), 157.1 (10), 145.1 (6). HRMS (EI, mixture): mass calcd for $\text{C}_{16}\text{H}_{16}\text{O}_2$: 188.1201; found: 188.1200.

(3S, 4R, 4R')-4-(2',2'-Dimethyl-[1',3']dioxolan-4'-yl)-3-methoxy-3-phenyl-oxetan-2-one 7a

(3R, 4S, 4R')-4-(2',2'-Dimethyl-[1',3']dioxolan-4'-yl)-3-methoxy-3-phenyl-oxetan-2-one 7b

Pentacarbonyl[(methoxy)(phenyl)methylene]chromium(0) (1.0 g, 3.1 mmol) was added to a flame dried pyrex pressure tube under argon atmosphere and dissolved into THF (25 mL). To the solution was added D-(R)-glyceraldehyde acetonide (1.7g, 12.7 mmol) and DMAP (48 mg, 0.34 mmol). The tube was then pressurized and purged with carbon monoxide (5 cycles) and then pressurized (30 psi). The tube was irradiated with a 450 watt medium pressure Hg lamp in a water cooled quartz immersion well for 14 h. The crude reaction mixture was then concentrated and chromatographed on silica gel (9:1, hexanes: EtOAc) to yield 321 mg (36%) of (3S, 4R, 4R')-4-(2',2'-Dimethyl-[1',3']dioxolan-4'-yl)-3-methoxy-3-phenyl-oxetan-2-one (**7a**) as a colorless oil and 245 mg (28%) of (3R, 4S, 4R')-4-(2',2'-Dimethyl-[1',3']dioxolan-4'-yl)-3-methoxy-3-phenyl-oxetan-2-one (**7b**) as a colorless oil as well as < 1% of the possible cis isomers. Spectral data for **7a**: $[\alpha]_D^{+84}$ (*c* 2.0; CHCl₃). ¹H NMR: (500 MHz) δ 7.44-7.39 (m, 5H), 4.69 (d, 1H, *J* = 7.2 Hz), 3.77 (dd, 1H, *J* = 8.5, 5.8 Hz), 3.72 (dt, 1H, *J* = 7.3, 5.8 Hz), 3.56 (dd, 1H, *J* = 8.3, 5.8 Hz), 3.34 (s, 3H), 1.40 (s, 3H), 1.17 (s, 3H). ¹³C NMR: (125 MHz) δ 167.7, 130.4, 129.8, 128.6, 128.1, 109.7, 94.4, 82.2, 72.9, 65.1, 53.6, 26.5, 25.0. IR (neat) 2986, 2939, 1834, 1495, 1253, 1128, 1072, 908, 841 cm⁻¹. MS (EI): 277.1 (M-H)⁺, 263.1 (20), 176.1 (40), 163.1 (54), 145.1 (50), 105.0 (100). HRMS: mass calcd for C₁₅H₁₇O₅ (M-H)⁺: 277.1076; found: 277.1078. Spectral data for **7b**: $[\alpha]_D^{-119}$ (*c* 2.0; CHCl₃). ¹H NMR: (500 MHz) δ 7.44-7.32 (m, 5H), 4.60 (d, 1H, *J* = 8.5 Hz), 3.72 (dt, 1H, *J* = 8.5, 6.7 Hz), 3.55 (dd, 1H, *J* = 8.5, 6.7 Hz), 3.38-3.34 (m, 4H), 1.37 (s, 3H), 1.17 (s, 3H). ¹³C NMR: (125 MHz) δ 167.7, 130.4, 129.9, 129.0, 126.9, 110.2, 93.8, 84.2, 74.3, 64.8, 53.9, 26.3, 24.9. IR (neat) 2988, 2941, 1832, 1450, 1382, 1263, 1136, 1069, 846 cm⁻¹. MS (EI): 277.1 (M-H)⁺, 263.1 (35), 176.1 (86), 163.1 (92), 145.1 (80), 105.0 (100). HRMS: mass calcd for C₁₅H₁₇O₅ (M-H)⁺: 277.1076; found: 277.1085.

(1'R, 3S, 4R)-4-(1',2'-Dihydroxy-ethyl)-3-methoxy-3-phenyl-oxetan-2-one

(3S, 4R, 4R')-4-(2',2'-Dimethyl-[1',3']dioxolan-4'-yl)-3-methoxy-3-phenyl-oxetan-2-one (**7a**) (80 mg, 0.3 mmol) was added to a flame dried 10 mL flask under argon atmosphere and dissolved into methanol (5 mL). To the solution was added catalytic *p*-toluenesulfonic acid. The contents of the flask were stirred at reflux for 3 h until the starting material was consumed by TLC. The crude reaction mixture was then concentrated and chromatographed on silica gel (6:4, hexanes: EtOAc) to yield 40 mg (~59%) of chromatographically unstable (1'R, 3S, 4R)-4-(1',2'-dihydroxy-ethyl)-3-methoxy-3-phenyl-oxetan-2-one as a white solid and 20 mg (29%) of (3R, 4R, 5R)-4-Hydroxy-5-hydroxymethyl-3-methoxy-3-phenyl-dihydro-furan-2-one (**8**) as a white solid, and < 1% of the two trans diastereomers. Partial characterization: ¹H NMR: (500 MHz) δ 7.44 (m, 5H), 4.60 (d, 1H, *J* = 9.7 Hz), 3.62 (dd, 1H, *J* = 11.6, 3.1 Hz), 3.58 (dd, 1H, *J* = 11.6, 5.0 Hz), 3.40 (s, 3H), 3.21 (ddd, 1H, *J* = 9.6, 5.0, 3.2 Hz), 2.22 (br, 2H). ¹³C NMR: (125 MHz) δ 167.8, 130.6, 129.9, 128.9, 127.6, 95.3, 80.9, 68.9, 62.4, 54.0. IR (neat) 3236, 2941, 2835, 1832, 1448, 1261, 1128, 1049, 918 cm⁻¹. MS (EI): 238.1 (M)⁺, 179.1 (15), 163.1 (100), 149.1 (7), 105.0 (100). HRMS: mass calcd for C₁₂H₁₄O₅ (M)⁺: 238.0841; found: 238.0840.

(3R, 4R, 5R)-4-Hydroxy-5-hydroxymethyl-3-methoxy-3-phenyl-dihydro-furan-2-one 8

(2'R, 3S, 4R)-4-(1',2'-Dihydroxy-ethyl)-3-methoxy-3-phenyl-oxetan-2-one (38 mg, 0.2 mmol) was dissolved in 3 mL of (1:1) hexanes : EtOAc in a 5 mL flask. 500 mg of SiO₂ was added and the slurry was stirred for 5 d at rt. Crude ¹H NMR indicated a 10:1 ratio of (3R, 4R, 5R)-4-Hydroxy-5-hydroxymethyl-3-methoxy-3-phenyl-dihydro-furan-2-one (**8**) to starting material. The crude slurry was then filtered through a fritted funnel and concentrated *in vacuo*. Chromatography on silica gel (6:4, hexanes:EtOAc) yielded 34 mg (89 %) of (3R, 4R, 5R)-4-Hydroxy-5-hydroxymethyl-3-methoxy-3-phenyl-dihydro-furan-2-one (**8**) as a white solid. [α]_D +107° (*c* 0.255; CHCl₃). ¹H NMR: (500 MHz) δ 7.47-7.38 (m, 5H), 4.41 (ddd, 1H, *J* = 7.9, 4.0, 2.8 Hz), 4.16 (dd, 1H, *J* = 10.5, 7.9 Hz), 4.01 (ddd, 1H, *J* = 12.5, 6.7, 2.8 Hz), 3.78 (ddd, 1H, *J* = 12.5, 6.7, 4.0 Hz), 3.37 (s, 3H), 3.04 (d, 1H, *J* = 10.4 Hz), 2.10 (t, 1H, *J* = 6.7 Hz). ¹³C NMR:

(125 MHz) δ 170.6, 134.0, 128.8, 128.7, 126.6, 82.5, 80.5, 75.8, 60.1, 53.5. IR (neat) 3503, 3346, 2981, 2939, 1763, 1448, 1091, 1033, 968 cm^{-1} . MS (EI): 238.1 (M)⁺, 165.1 (100), 119.1 (8), 105.0 (28). HRMS: mass calcd for C₁₂H₁₄O₅ (M)⁺: 238.0841; found: 238.0838.

¹H NMR Spectra

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DS 4
SWH 8064.313 MHz
FIDRES 0.123044 Hz
AQ 4.063218 sec
RG 327.68
DW 62.000 nsec
DE 88.000 nsec
TE 300.2 K
D1 2.000000 sec
P1 7.00 nsec
SF01 400.132418 MHz
NUCLEUS 13C

F2 - Processing parameters
SI 65536
SF 400.130018 MHz
WDW EM
SSB 0
LB 0.300 Hz
GB 0
PC 1

1D NMR plot parameters
CX 20
F1P 9.4
F1 3761.435 MHz
F2P -0.6
F2 -240.130 MHz
PPMCM 0.500
HZCM 200.062

Default proton parameters

Current Data
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F2 - Acquisition
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Current Data Parameters
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SWH 10
FIDRES 0
AQ 1.
RG
DW
DE
TE
D1 2.0

===== CHANNEL 1 =====
NUC1
P1
PL1
SF01 500.

F2 - Processing
SI
SF 500.
WDW
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PC

1D NMR plot parameters
CX
F1P
F1
F2P
F2
PPMCM
HZCM 25

Default proton parameters

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1D NMR plo
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HZCM