Supplementary information

Remarkable co-catalyst effects on the enantioselective hydrogenation of unfunctionalised enamines: both enantiomers of product from the same enantiomer of catalyst

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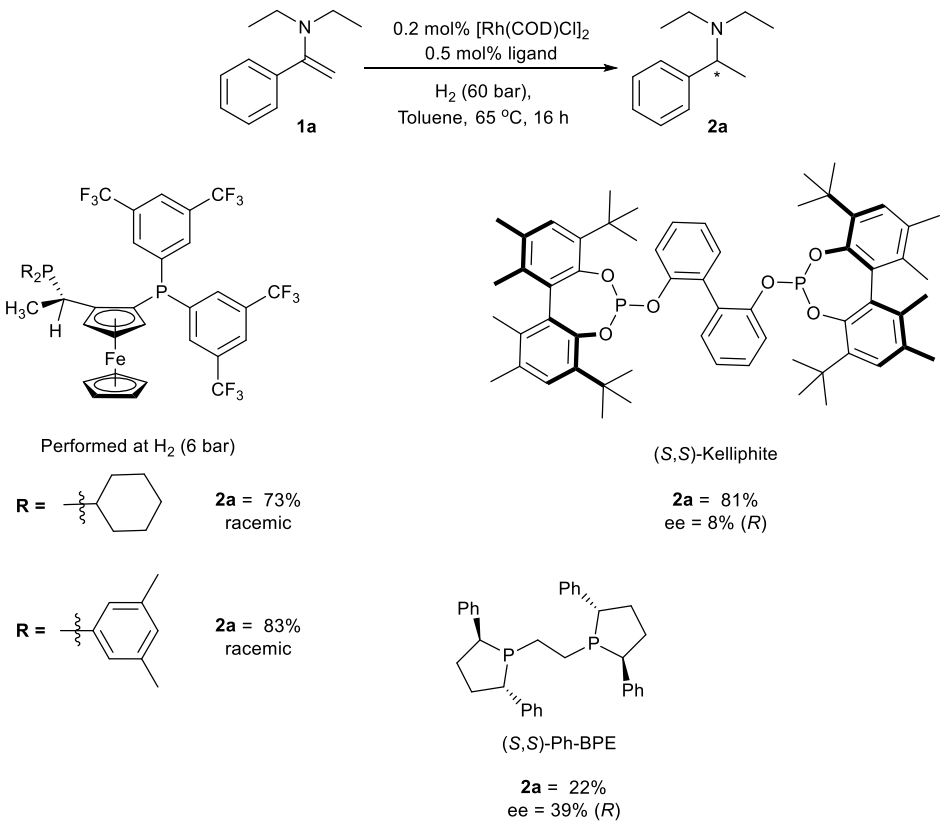
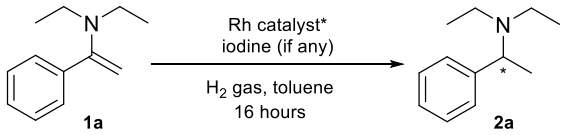
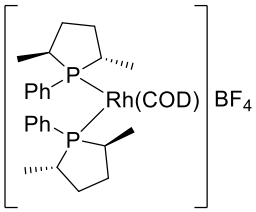
Data from catalytic experiments performed in chlorobenzene + additional data.

Scheme ESI 1. Several examples of performance of ligands in Rh-catalysed enantioselective hydrogenation of enamine **1a** (performed in high-pressure autoclave).



Scheme ESI 2. Examples of Rh catalysts for hydrogenation of enamine **1a** (performed in Biotage Endeavor Catalyst Screening System (Argonaut)).

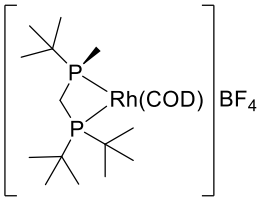




[((*S*,*S*)-Me-Phospholane)Rh(COD)]BF_4

Rh loading = 0.4 mol%, 50 °C

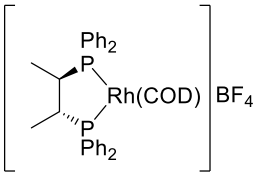
no I_2	0.8 mol% I_2
H_2 (20 bar)	H_2 (20 bar)
2a = 17%	**2a** > 99%
racemic	racemic



[((*R*)-TCFP)Rh(COD)]BF_4

Rh loading = 0.4 mol%, 50 °C

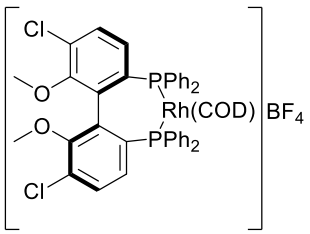
no I_2	0.8 mol% I_2
H_2 (20 bar)	H_2 (20 bar)
2a = 60%	**2a** > 99%
racemic	racemic



[((*R*,*R*)-Chiraphos)Rh(COD)]BF_4

Rh loading = 0.4 mol%, 50 °C

no I_2	0.8 mol% I_2
H_2 (20 bar)	H_2 (20 bar)
2a = 71%	**2a** = 29%
ee = 37% (*S*)	ee = 15% (*R*)

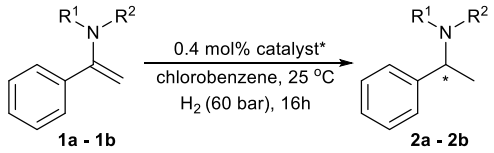


[((*R*)-Cl-MeO-BiPhen)Rh(COD)]BF_4

Rh loading = 0.9 mol%, 65 °C

no I_2	1.8 mol% I_2
H_2 (27 bar)	H_2 (28 bar)
2a > 99%	**2a** > 99%
racemic	racemic

Table ESI 1. Data for the Charts 1 and 2.



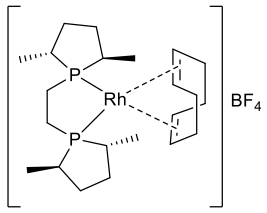
1a - 1b **2a - 2b**

1a: $R^1 = R^2 = Et$
1b: $R^1 = Me$, $R^2 = Bn$

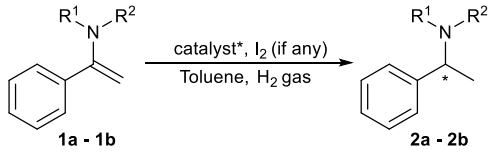
Entry[a]	Enamine	Catalyst	I_2, mol%	Amine, %[b]	ee, %[c,d]
1	**1a**	(*R*,*R*)-**3**	-	**93** [60][f]	58 (*R*)
2	**1a**	(*R*,*R*)-**3**	0.8	**> 99** [71][f]	58 (*S*)
3	**1a**	(*R*,*R*)-**4**	-	**47**	73 (*R*)
4	**1a**	(*R*,*R*)-**4**	0.8	**> 99**	61 (*S*)
5	**1b**	(*R*,*R*)-**3**	-	**74**	39 (*R*)
6	**1b**	(*R*,*R*)-**3**	0.8	**> 99** [82][f]	59 (*S*)
7	**1b**	(*R*,*R*)-**4**	-	**35**	50 (*R*)
8	**1b**	(*R*,*R*)-**4**	0.8	**98**	74 (*S*)
9[e]	**1b**	(*R*,*R*)-**3**	0.1	**54**	53 (*S*)

[a]General conditions: 1 mmol of enamine, 0.4 mol% of Rh, 0.1 mL of 1-methylnaphthalene as an internal standard, 60 bar of H_2 gas, 25 °C, chlorobenzene as a solvent (2 mL), 16 hours. [b]Determined by ^{1}H NMR relative to 1-methylnaphthalene. [c]Enantiomeric excess determined by ^{1}H NMR after addition an excess of (*R*)-(–)-α-methoxyphenylacetic acid. [d]Stereochemistry assigned after comparison to an authentic sample of chiral amine. [e]0.05 mol% of Rh catalyst, T=40 °C, scale is 8 mmol of enamine, 16 mL of chlorobenzene used. [f][Isolated yield] (optical rotation was recorded as well where the sing was in accordance with NMR assignment of the enantiomer formed).

Table ESI 2. Further catalytic experiments performed in toluene.



[((*R*,*R*)-Me-BPE)Rh(COD)]BF_4 (**5**)



1a: $R^1 = R^2 = Et$
1b: $R^1 = Me$, $R^2 = Bn$

Entry [a]	Enamine	Catalyst, mol%	Iodine, mol%	Time, hours	T, °C	P, bar	Amine, %[b,c]	ee, %[e,f]
1	**1a**	(*S*,S)-**3**, 0.4	0.8	18	65	5	54	50 (*R*)
2	**1a**	(*S*,S)-**3**, 0.4	0.8	18	65	10	74	47 (*R*)
3	**1a**	(*S*,S)-**3**, 0.4	0.8	18	65	20	> 99	39 (*R*)
8	**1a**	(*R*,*R*)-**5**, 1.0	2.0	18	65	20	97[d]	40 (*S*)
9	**1a**	(*R*,*R*)-**5**, 1.0	2.0	2	65	20	98[d]	36 (*S*)
10	**1a**	(*R*,*R*)-**5**, 0.4	-	16	50	20	80	racemic
11	**1a**	(*R*,*R*)-**5**, 0.4	0.8	16	50	20	99[d]	40 (*S*)
12[g]	**1a**	(*R*,*R*)-**5**, 0.05	0.1	16	50	20	56	38 (*S*)
13[g]	**1a**	(*R*,*R*)-**5**, 0.1	0.2	16	25	20	56	47 (*S*)
14	**1b**	(*R*,*R*)-**5**, 0.4	-	16	30	20	39	23 (*R*)
15	**1b**	(*R*,*R*)-**5**, 0.4	0.8	16	30	20	92[d]	40 (*S*)
16[g]	**1b**	(*R*,*R*)-**5**, 0.05	0.1	16	50	20	90	34 (*S*)
17[h]	**1b**	(*R*,*R*)-**3**, 0.4	-	16	25	60	30	29 (*R*)
18[h]	**1b**	(*R*,*R*)-**4**, 0.4	-	16	25	60	11	21 (*R*)

[a]General conditions: reactions performed in Argonaut, 2 mmol of enamine, Rh catalyst, iodine (if any), 0.1 mL of 1-methylnaphthalene as an internal standard, H_2 gas, toluene as a solvent (5 mL). [b]The only side product observed is a ketone which is formed due to partial hydrolysis of enamine. [c]Determined by ^1H NMR relative to 1-methylnaphthalene. [d]Full consumption of enamine. [e]Enantiomeric excess determined by ^1H NMR after addition an excess of (*R*)-(–)-α-methoxyphenylacetic acid. [f]Stereochemistry of amines was assigned after comparison to authentic samples of chiral amines. [g]Reaction scale is 7.8 mmol, solution volume 7.8 mL.[h]Performed in microwave vials in high pressure autoclave at 1.0 mmol scale of enamine.

General experimental techniques

All hydrogenation procedures were carried out under inert conditions using standard schlenk techniques, and all solvents used were dried and degassed. The reactor for hydrogenation processes was a high pressure autoclave or Argonaut (Biotage Endeavor Catalyst Screening System).

Synthetic procedures to prepare enamines using $TiCl_4$ were carried out in dry solvents under a nitrogen atmosphere. Work-ups of these reactions, as well as isolation of amines, were done under aerobic conditions. All materials were used as received, unless otherwise stated.

Racemic samples of amines were prepared according to the literature procedures reported previously.[1] Rh complexes were supplied by Dr Reddy's. Other materials were purchased from Sigma Aldrich or Acros and were used without further purification.

All NMR spectra were acquired on Bruker Avance 500 (^{1}H at 500 MHz), Bruker Avance 400 (^{1}H at 400 MHz, ^{13}C at 100 MHz) or Bruker Avance 300 (^{1}H at 300 MHz, ^{13}C at 75 MHz).

Mass spectroscopy and high-resolution mass spectroscopy were carried out by Mrs Caroline Horsburgh at the University of St Andrews.

Optical rotations were recorded on a Perkin elmer 341 polarimeter using a 1 mL cell with 1 dm path length and Na D-line at 20 ^{o}C.

Hydrogenation of enamines.

General procedure for enamine hydrogenation in high pressure autoclave.

A high pressure autoclave with 4 vials was used. A vial was charged with the desired Rh complex (4.0 μmol), sealed and purged with Ar for 10 minutes. Solution of iodine in solvent used (8.0 mM, 1.0 mL, 8.0 μmol) was added. In case if iodine was not used, solvent (1.0 mL) was added instead of iodine solution. This was left to stir for 10 minutes before a toluene solution of the desired enamine (1.0 mL, 1M, contains 1.0 mmol of enamine and 0.1 mL of 1-methylnaphthalene) was added and the resulting solution was stirred for 5 minutes. After this time, the vial placed into the pre-purged autoclave, the autoclave was sealed, purged with hydrogen 3 times, pressurised with H_2 gas to the desired pressure, heated to the desired temperature and left to stir for 16 hours. After this time, the autoclave was cooled to room temperature, the gas pressure was released and ^{1}H NMR of the crude reaction solution was acquired in order to calculate the conversion.

For ee determination, a sample of the crude solution (containing 0.08 mmol of enamine / ketone / amine mixture) was left *in vacuo* for 5 minutes to remove toluene, and (*R*)-(–)-α-methoxyphenylacetic (0.020 g, 0.12 mmol) was added, dissolved in DCM (0.5 mL) and ^{1}H NMR on Bruker Avance 500 was acquired with C_6D_6 capillary to measure the enantiomeric excess of the amine.

General procedure for enamine hydrogenation in Argonaut (2 mmol scale).

An Argonaut vial was charged with the desired Rh complex, sealed and purged with N_2 gas 3 times. Solution of I_2 (2 equivalents relative to Rh) in toluene (1 mL) was added. In case if iodine was not used, toluene (1 mL) was added instead of iodine solution. The vial was purged with nitrogen gas 3 times and a toluene solution of the desired enamine (2.0 mL, 1M, contains 2.0 mmol of enamine and 0.2 mL of 1-methylnaphthalene) was added followed by addition of toluene (2 mL). The vial was purged with nitrogen gas 3 times, then purged with hydrogen gas 3 times and the Argonaut was programmed to run for the desired time at the desired pressure of H_2 gas at the desired temperature at rotation speed of the stirrer of 1000 rpm. After this time, the Argonaut switches stirring off and cools to room temperature. The gas pressure was released and ^{1}H NMR of the crude reaction solution was acquired in order to calculate the conversion.

For ee determination, a sample of the crude solution (containing 0.08 mmol of enamine / ketone / amine mixture) was left *in vacuo* for 5 minutes to remove toluene, and (*R*)-(–)-α-methoxyphenylacetic (0.020 g, 0.12 mmol) was added, dissolved in DCM (0.5 mL) and ^{1}H NMR on Bruker Avance 500 was acquired with C_6D_6 capillary to measure the enantiomeric excess of the amine.

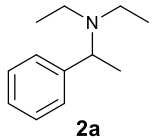
Isolation of amines.

General procedure (performed for several examples).

After catalytic hydrogenation of enamine and removal of 8% of the product mixture for determination of ee, the solution was diluted with toluene (8 mL). The amine was extracted with hydrochloric acid (1M, 3 x 20 mL). Combined acid fractions were basified with aq. NaOH (1M) to pH = 12, and the amine was extracted with ethyl acetate (3 x 25 mL). Combined organic fractions were washed with brine (30 mL), dried over $MgSO_4$ and solvent was removed under reduced pressure. The desired product was dried *in vacuo* for 50 minutes to afford the desired amine.

Example from Table ESI1 entry 2.

N,*N*-diethyl-1-phenylethanamine (**2a**)[2]



2a

The product is a pale-yellow oil (116 mg, 0.65 mmol, 71%).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ_H = 7.38 – 7.19 (5H, m, Ar-H), 3.79 (1H, q, $^{3}J_{HH}$ = 6.7 Hz, CH), 2.63 – 2.45 (4H, m, 2 x CH_2), 1.33 (3H, d, $^{3}J_{HH}$ = 6.8 Hz, CH-CH_3), 0.99 (6H, t, $^{3}J_{HH}$ = 7.1 Hz, 2 x -CH_2-CH_3).

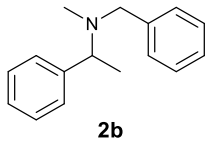
^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ_C = 145.3 (^{Ar}C), 128.0 (s, ^{Ar}CH), 127.6 (s, ^{Ar}CH), 126.5 (s, ^{Ar}CH), 59.2 (s, N-CH), 42.8 (s, CH_2), 18.4 (s, CH-CH_3), 12.1 (s, CH_2-CH_3).

MS (ES^+) *m/z*: 178.16 ($[MH]^+$, 86%), 105.07 ($[M - NEt_2]^+$, 100); Found(ES^+) 178.1586 ($[MH]^+$), $C_{12}H_{20}N^+$ requires 178.1590.

$[\alpha]_D^{20}$ = -4.3 (*c* 0.8, $CHCl_3$).

Example from Table ESI1 entry 6.

N-benzyl-*N*-methyl-1-phenylethanamine (**2b**)[2]



2b

The product is a very viscous yellow oil (169 mg, 0.75 mmol, 82%).

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ_H = 7.38 – 7.14 (10H, m, Ar-H), 3.59 (1H, q, $^{3}J_{HH}$ = 6.9 Hz, N-CH), 3.53 (1H, d, $^{2}J_{HH}$ = 13.3 Hz, one of CH_2), 3.25 (1H, d, $^{2}J_{HH}$ = 13.3 Hz, one of CH_2), 2.08 (3H, s, N-CH_3), 1.37 (3H, d, $^{3}J_{HH}$ = 6.7 Hz, CH-CH_3).

^{13}C NMR (100 MHz, $CDCl_3$, 298 K): δ_C = 144.1 (s, ^{Ar}C), 140.0 (s, ^{Ar}C), 128.7 (s, ^{Ar}CH), 128.1 (2 x C, s, ^{Ar}CH), 127.7 (s, ^{Ar}CH), 126.8 (s, ^{Ar}CH), 126.7 (s, ^{Ar}CH), 63.2 (s, N-CH), 58.8 (s, CH_2), 38.3 (s, N-CH_3), 18.4 (s, CH-CH_3).

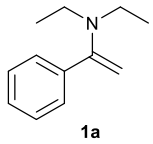
MS (ES^+) *m/z*: 226.16 ($[MH]^+$, 100%).

$[\alpha]_D^{20}$ = -10.1 (*c* 0.9, $CHCl_3$).

Synthetic procedures.

Enamines were prepared using literature procedure previously reported.[3]

N,*N*-diethyl-1-phenylethenamine (**1a**)[2]



1a

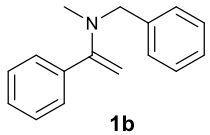
A hexane solution (100 mL) of acetophenone (5.0 mL, 42.9 mmol) and diethyl amine (27.0 mL, 260 mmol) was cooled to 0 ^{o}C and $TiCl_4$ (2.6 mL, 23.7 mmol) was added dropwise and the resulting suspension was left to stir for further 30 minutes followed by stirring the reaction mixture at room temperature for further 24 hours. After this time, the flask was opened to air and the solution was filtered and volatiles were removed *in vacuo*. The product was purified by distillation under reduced pressure (90 ^{o}C, 1.5 mbar) to afford the desired enamine (4.043 g, 23.1 mmol, 54%) as a pale yellow liquid.

^{1}H NMR (300 MHz, C_6D_6, 298 K): δ_H = 7.28 – 7.20 (2H, m, Ar-H), 6.92 – 6.78 (3H, m, Ar-H), 4.13 (1H, s, one of C=CH_2), 3.91 (1H, s, one of C=CH_2), 2.58 (4H, q, $^{3}J_{HH}$ = 7.0 Hz, 2 x N-CH_2), 0.61 (6H, t, $^{3}J_{HH}$ = 7.0 Hz, 2 x CH_3) .

^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$, 298 K): δ_C = 154.4 (s, N-C), 141.6 (s, ^{Ar}C), 128.5 (s, ^{Ar}CH), 128.4 (s, ^{Ar}CH), 128.1 (s, ^{Ar}CH), 90.9 (s, C=CH_2), 43.7 (s, N-CH_2), 12.1 (s, CH_3).

MS (ES^{+}) *m/z*: 176.14 ([MH]$^{+}$, 100%); Found(ES^{+}) 176.1430 ([MH]$^{+}$), $C_{12}H_{18}N^{+}$ requires 176.1434.

N-benzyl-*N*-methyl-1-phenylethenamine (**1b**)[2]



1b

A hexane solution (300 mL) of acetophenone (12.0 mL, 102 mmol) and *N*-methylbenzylamine (79.0 mL, 612 mmol) was cooled to 0 ^{o}C and $TiCl_4$ (6.2 mL, 56.5 mmol) was added dropwise and the resulting suspension was left to stir for further 30 minutes followed by stirring the reaction mixture at room temperature for further 24 hours. After this time, the flask was opened to air and water-saturated diethyl ether (62 mL) was added. The solution was filtered and volatiles were removed *in vacuo*. The product was purified by

distilling impurities of under reduced pressure (95 ^{o}C, 1.5 mbar, 40 minutes) to afford the desired enamine (13.462 g, 60.3 mmol, 59%) as very viscous brown oil.

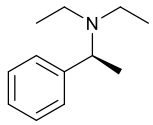
^{1}H NMR (300 MHz, C_6D_6, 298 K): δ_H = 7.35 – 7.29 (2H, m, Ar-H), 6.92 – 6.74 (8H, m, Ar-H), 4.12 (1H, s, one of C=CH_2), 3.89 (1H, s, one of C=CH_2), 3.56 (2H, s, N-CH_2), 2.13 (3H, s, CH_3).

^{13}C NMR (75 MHz, $CDCl_3$, 298 K): δ_C = 156.9 (s, N-C), 140.3 (s, ^{Ar}C), 138.9 (s, ^{Ar}C), 128.5 – 128.0 (m, ^{Ar}CH), 90.4 (s, C=CH_2), 57.0 (s, N-CH_2), 38.1 (s, CH_3).

MS (ES^+) *m/z*: 224.14 ($[MH]^+$, 100%), 122.10 ($[MH_2 – C_8H_7]^+$, 70), 91.05 ($[C_7H_7]^+$, 41).

Synthesis of authentic chiral samples of amines (*S*)-**2a** and (*R*)-**2b**.

Synthesis of (*S*)-*N*,*N*-diethyl-1-phenylethanamine (prepared according to modified literature procedure)[4]



(*S*)-**2a**

To a suspension of sodium carbonate (1.00 g) in ethanol (24 mL) (*S*)-1-phenylehtanamine (1.0 mL, 7.76 mmol) was added followed by dropwise addition of ethyl iodide (1.4 mL, 17.4 mmol) over 10 minutes. The resulting mixture heated to 45 ^{o}C and left to stir overnight. After this time, ethanol was removed under reduced pressure, water (25 mL) and diethyl ether (30 mL) were added, the biphasic mixture stirred for 10 minutes, organic layer separated, dried over $MgSO_4$, solvent was removed under reduced pressure to afford a mixture of products (major product is (*S*)-*N*-ethyl-1-phenylethanamine). The desired product was isolated by silica column (EtOAc : Pet. Ether : Et_3N – 1 : 1 : 0.05 as an eluting solvent, R_f = 0.67) as a colourless oil (0.081 g, 6%).

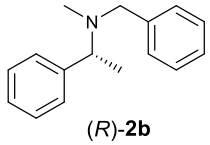
$[\alpha]_D^{20}$ = -16.9 (*c* 1.0, $CHCl_3$).

^{1}H NMR (300 MHz, $CDCl_3$, 298 K): δ_H = 7.31 – 7.07 (5H, m, Ar-H), 3.70 (1H, q, $^{3}J_{HH}$ = 6.7 Hz, CH), 2.57 – 2.33 (4H, m, 2 x CH_2), 1.25 (3H, d, $^{3}J_{HH}$ = 6.7 Hz, CH-CH_3), 0.90 (6H, t, $^{3}J_{HH}$ = 7.1 Hz, 2 x -CH_2-CH_3).

^{13}C NMR (75 MHz, $CDCl_3$, 298 K): δ_C = 145.3 (^{Ar}C), 128.1 (s, ^{Ar}CH), 127.6 (s, ^{Ar}CH), 126.5 (s, ^{Ar}CH), 59.2 (s, N-CH), 42.9 (s, CH_2), 18.5 (s, CH-CH_3), 12.2 (s, CH_2-CH_3).

MS (ES^+) *m/z*: 178.16 ($[MH]^+$, 86%), 105.07 ($[M – NEt_2]^+$, 100); Found(ES^+) 178.1586 ($[MH]^+$), $C_{12}H_{20}N^+$ requires 178.1590.

Synthesis of (*R*)-*N*-benzyl-*N*-methyl-1-phenylethanamine (modified literature procedure was used)[5]



(*R*)-**2b**

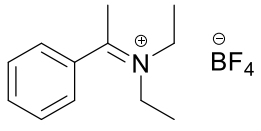
To a solution of (*R*)-*N*-methyl-1-phenylethanamine (1.0 mL, 6.83 mmol) in ethanol (15 mL) benzaldehyde (0.8 mL, 7.88 mmol) was added. The resulting solution was stirred for 5 minutes and sodium acetoxyborohydride (1.732 g, 8.17 mmol) was added and the mixture was left to stir overnight. After this time, ethanol was removed under reduced pressure, the crude mixture was suspended in toluene and extracted with hydrochloric acid (1M, 3 x 25 mL). Combined acid layers were basified with aqueous NaOH (1M) to pH = 12, extracted with ethyl acetate (3 x 25 mL), the organic layers were combined and dried over $MgSO_4$. The solvent was removed under reduced pressure to afford a mixture of the desired product and *N*-methylbenzyl amine. The desired product was isolated by silica column (EtOAc : Pet. Ether : Et_3N – 1 : 3 : 0.05 as an eluting solvent) as a pale-yellow viscous oil (0.616 g, 40%).
$[\alpha]_D^{20}$ = +25.3 (*c* 1.0, $CHCl_3$).

^{1}H NMR (300 MHz, $CDCl_3$, 298 K): δ_H = 7.36 – 7.09 (10H, m, Ar-H), 3.55 (1H, q, $^3J_{HH}$ = 6.7 Hz, N-CH), 3.49 (1H, d, $^2J_{HH}$ = 13.2 Hz, one of CH_2), 3.21 (1H, d, $^2J_{HH}$ = 13.2 Hz, one of CH_2), 2.05 (3H, s, N-CH_3), 1.33 (3H, d, $^3J_{HH}$ = 6.7 Hz, CH-CH_3).

^{13}C NMR (75 MHz, $CDCl_3$, 298 K): δ_C = 144.1 (s, ^{Ar}C), 140.0 (s, ^{Ar}C), 128.7 (s, ^{Ar}CH), 128.2 (2 x C, s, ^{Ar}CH), 127.7 (s, ^{Ar}CH), 126.8 (s, ^{Ar}CH), 126.7 (s, ^{Ar}CH), 63.2 (s, N-CH), 58.8 (s, CH_2), 38.3 (s, N-CH_3), 18.4 (s, CH-CH_3).

MS (ES^+) *m/z*: 226.16 ($[MH]^+$, 100%).

Synthesis of *N*-(1-phenylethylidene)diethylammonium tetrafluoroborate (prepared according to the literature procedure)[6]



A solution of *N*,*N*-diethyl-1-phenylethenamine (3.85 g, 22.0 mmol) in diethyl ether (40 mL) was cooled to -10 ^oC and $HBF_4 \cdot Me_2O$ (2.7 mL, 22.2 mmol) was added dropwise. The solution was left to warm to RT and left to stir overnight. After this time, the oily product

settled on the bottom. The diethyl ether was removed by cannula, the oil was washed with diethyl ether (3 x 15 mL) and left to dry in vacuo for 4 hours to afford very viscous oily material (4.69 g, 17.8 mmol, 81%) as the desired product.

^{1}H NMR (400 MHz, $CDCl_3$, 298 K): δ_H = 7.54 – 7.46 (5H, m, Ar-H), 4.12 (2H, q, $^{3}J_{HH}$ = 7.4 Hz, CH_2), 3.77 (2H, q, $^{3}J_{HH}$ = 7.4 Hz, CH_2), 2.81 (3H, s, C-CH_3), 1.54 (3H, t, $^{3}J_{HH}$ = 7.4 Hz, CH_2-CH_3), 1.33 (3H, t, $^{3}J_{HH}$ = 7.3 Hz, CH_2-CH_3).

^{19}F NMR (377 MHz, $CDCl_3$, 298 K): δ_F = -151.6 (1F, s). -151.5 (3F, s).

^{13}C NMR (126 MHz, $CDCl_3$, 298 K): δ_C = 187.7 (N=C), 134.2 (^{Ar}C), 131.6 (^{Ar}CH), 129.4 (^{Ar}CH), 125.2 (^{Ar}CH), 52.0 (CH_2), 49.8 (CH_2), 26.0 (C-CH_3), 12.8 (CH_2-CH_3), 12.2 (CH_2-CH_3).

MS (ES^+) *m/z*: 176.14 ($[C_{12}H_{18}N]^+$, 86%); Found(ES^+) 176.1432 ($[C_{12}H_{18}N]^+$), $C_{12}H_{18}N^+$ requires 176.1434.

Mechanistic studies.

Reaction of [((*R*,*R*)-Et-BPE)-Rh(COD)]BF_4 with iodine.

The Rh complex (20 mg, 32.7 µmol) was dissolved in CD_2Cl_2 (0.6 mL)and a $^{31}P\{^{1}H\}$ NMR spectrum was acquired (Figure ESI 1, top spectrum). Iodine (8.3 mg, 32.7 µmol) was added to the NMR tube under inert conditions, the whole solution was mixed well for 5 minutes and $^{31}P\{^{1}H\}$ NMR spectrum was recorded (Figure ESI 1, middle spectrum). After this, additional iodine (8.3 mg, 32.7 µmol) was added and $^{31}P\{^{1}H\}$ NMR was acquired (Figure ESI 1, bottom spectrum).

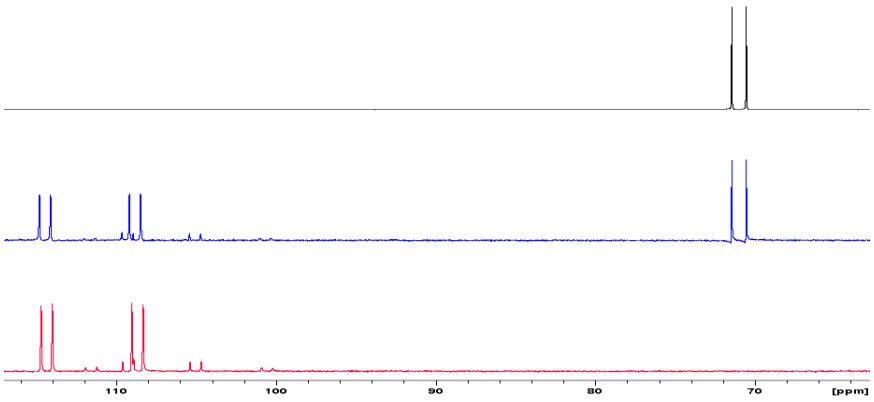


Figure ESI 1. $^{31}P\{^{1}H\}$ NMR spectra of catalyst (top), catalyst + 1 equivalent of iodine (middle) and catalyst + 2 equivalents of iodine (bottom).

Reaction of Rh-iodine dihydrogen complex with enamine **1a**.

[((*R*,*R*)-Et-DUPHOS)-Rh(COD)]BF_4 (20 mg, 30.3 μmol) and iodine (15.4 mg, 60.7 μmol) were charged into a microwave vial and the vial was flushed with argon for 10 minutes. The complex and iodine were dissolved in CD_2Cl_2 (0.6 mL), the vial was charged into a high pressure autoclave, the autoclave was pressurised with hydrogen gas (60 bar) and the content was left to stir for 3 hours. After this time, hydrogen pressure was released and a solution of *N*,*N*-diethyl-1-phenylethenamine (5.3 mg, 30.3 μmol) in CD_2Cl_2 (0.2 mL) was added. The resulting solution was immediately transferred to an NMR tube under argon, and ^{1}H NMR was acquired (Figure ESI 2, selected region in ^{1}H NMR – bottom spectrum). The solution contained no enamine, and no traces of amine were detected as well, while clear and diagnostic signals of the CH_2 groups of *N*-(1-phenylethylidene)diethylammonium cation were observed (slight difference in shift might be the effect of a different counter-ion).

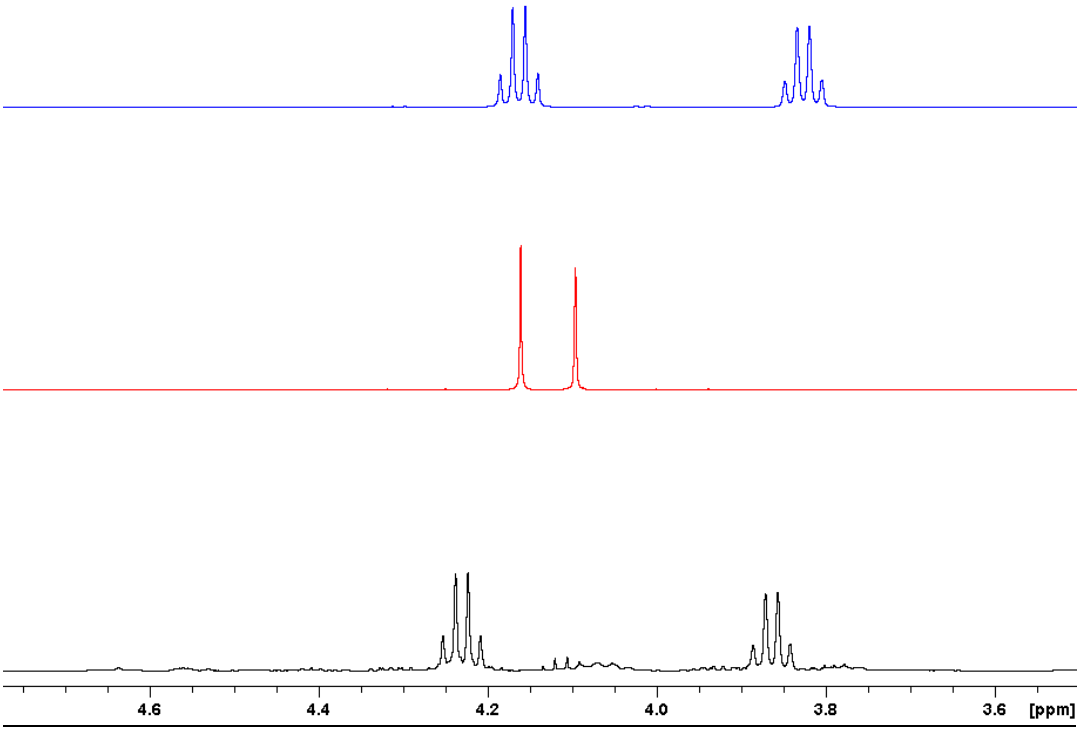


Figure ESI 2. ^{1}H NMR spectra in CD_2Cl_2 of the selected region of: *N*-(1-phenylethylidene)diethylammonium tetrafluoroborate (top spectrum), *N*,*N*-diethyl-1-phenylethenamine (middle spectrum) and the reaction between dihydrogen Rh-I complex with *N*,*N*-diethyl-1-phenylethenamine (bottom spectrum).

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6. H. Guan, M. Iimura, M.P. Magee, J.R. Norton, G. Zhu, *J. Am. Chem. Soc.*, 2005, **127**, 7805.

Additional NMR spectra.

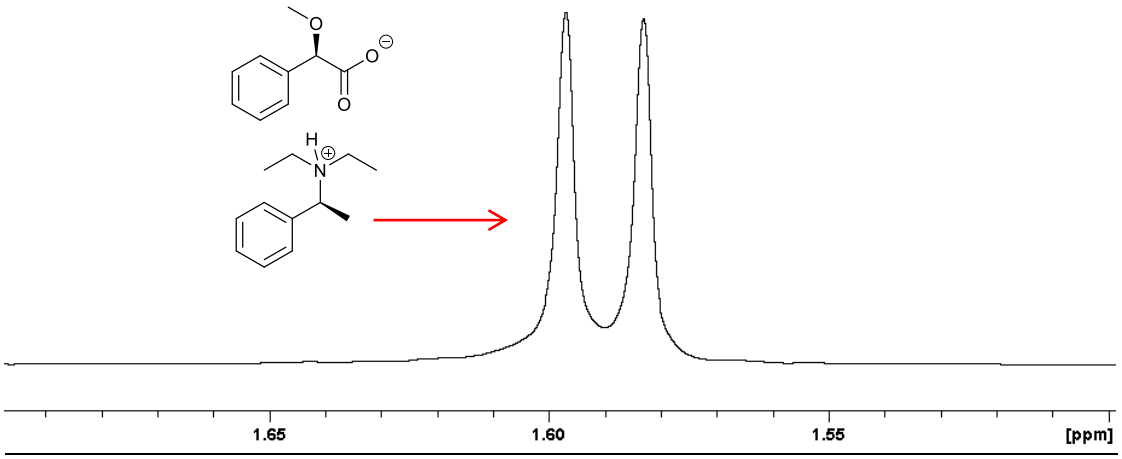

Figure ESI 3. Selected region of ^{1}H NMR spectrum of a sample of (*S*)-**2a** mixed with 1.2 equivalents of (*R*)-α-methoxyphenylacetic acid.

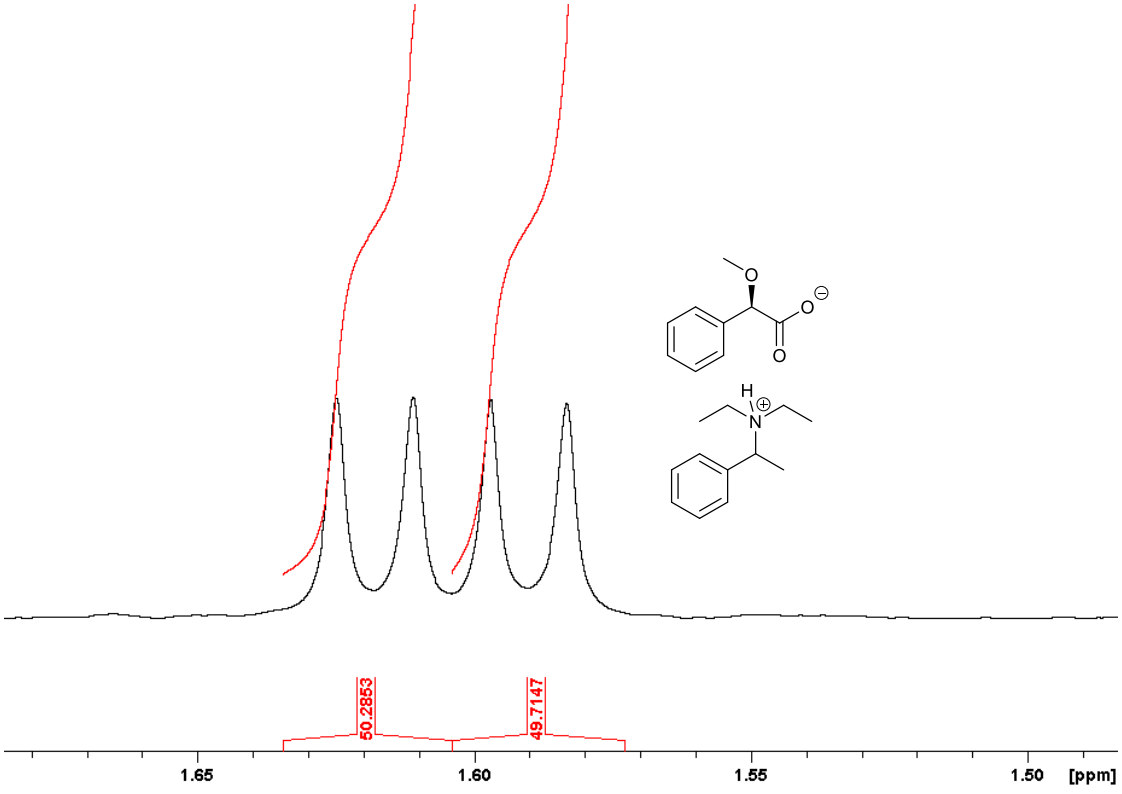

Figure ESI 4. Selected region of ^{1}H NMR spectrum of a sample of racemic **2a** mixed with 1.2 equivalents of (*R*)-α-methoxyphenylacetic acid.

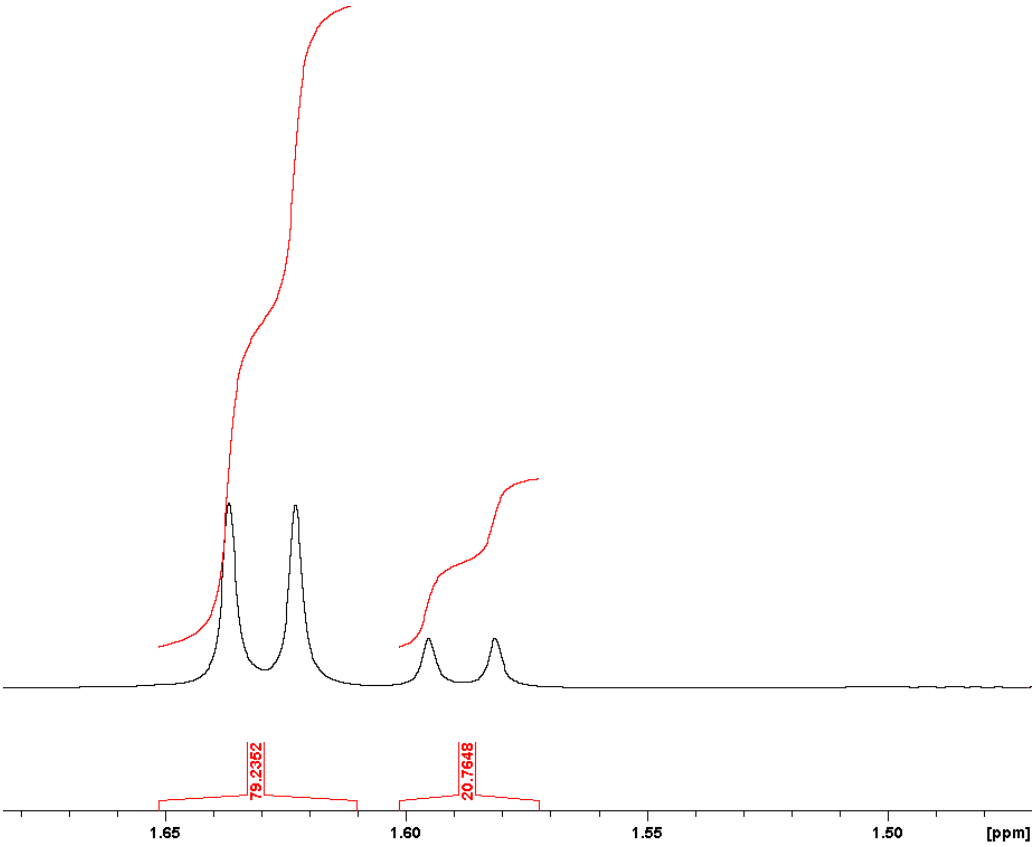

Figure ESI 5. An example of ee measurement – Table ESI 1 entry 1.

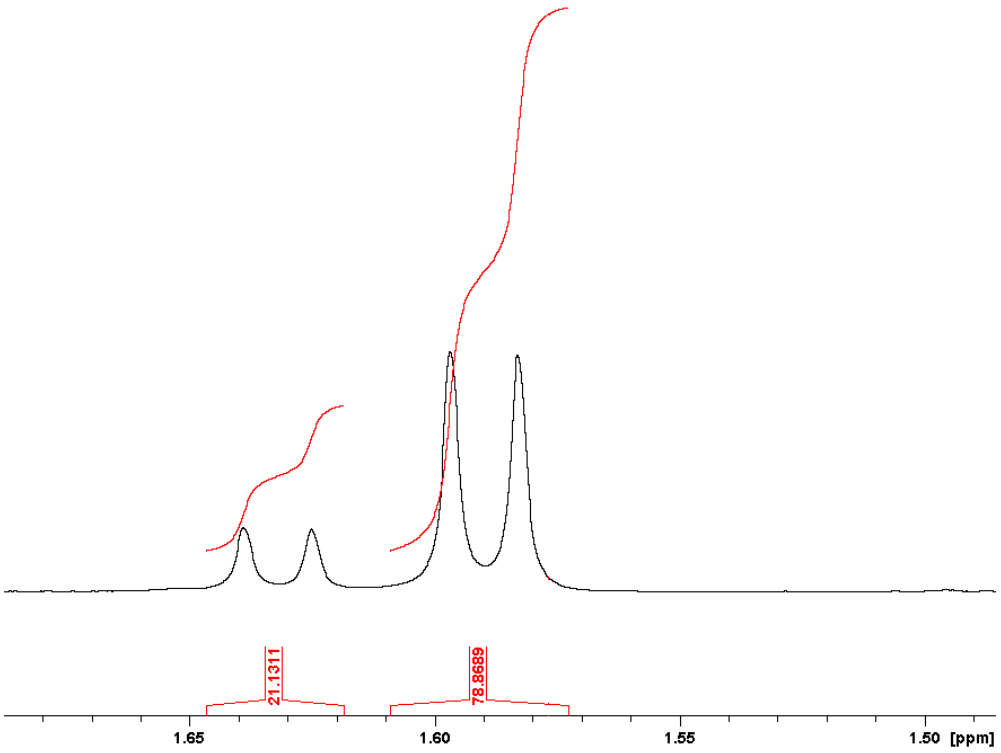

Figure ESI 6. An example of ee measurement – Table ESI 1 entry 2.

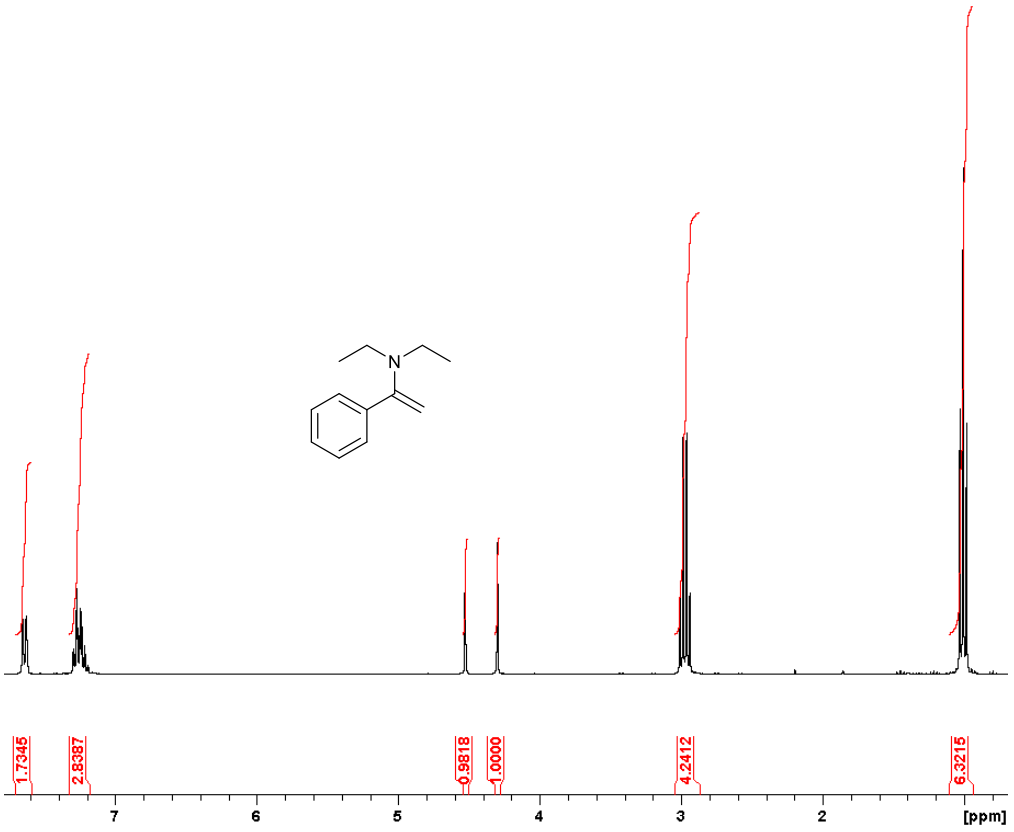

Figure ESI 7. ^{1}H NMR of enamine **1a**.

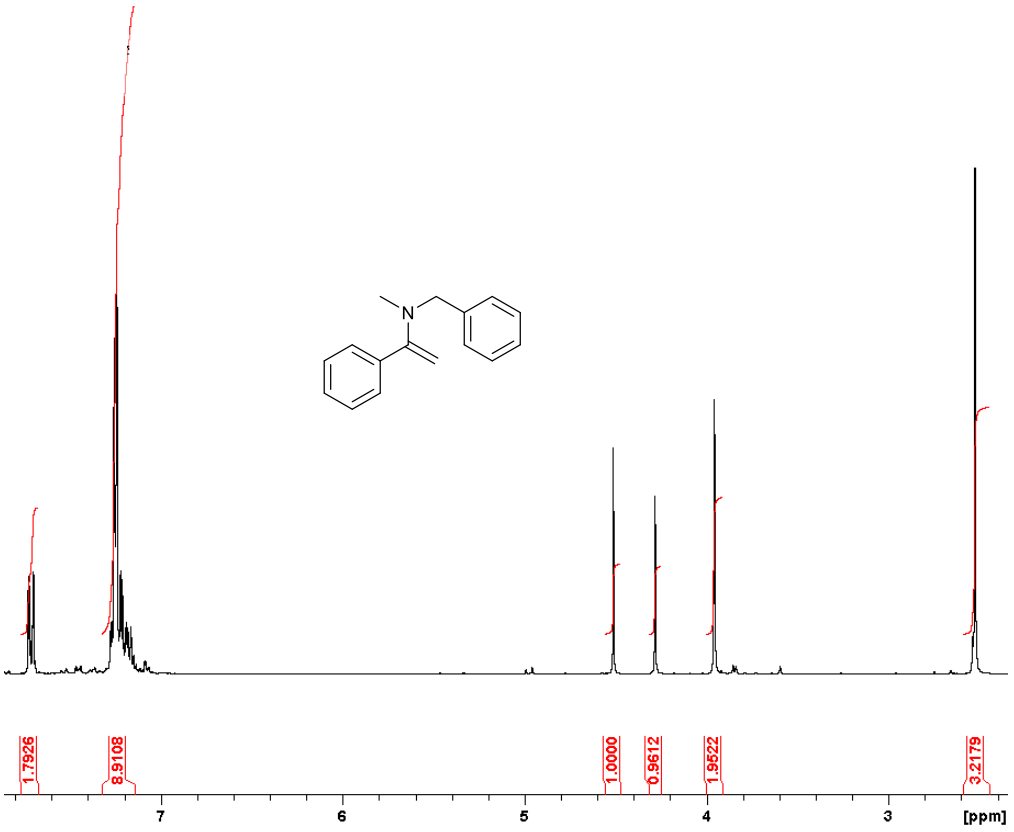

Figure ESI 8. ^{1}H NMR of enamine **1b**.

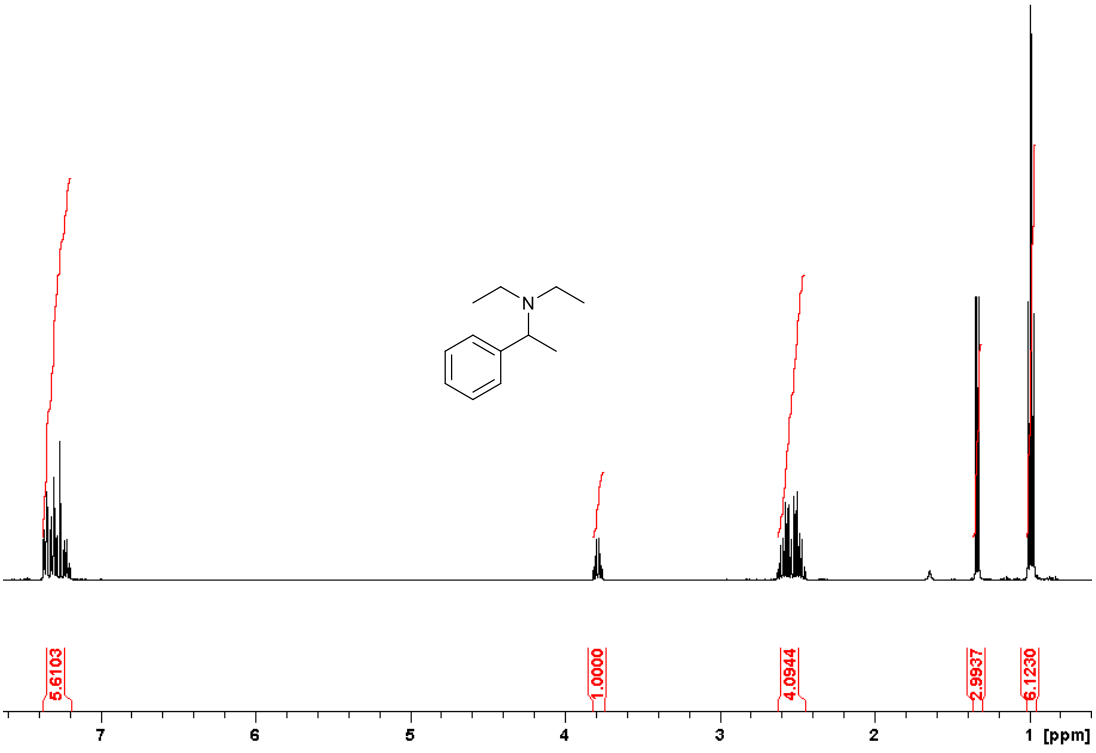

Figure ESI 9. [1]H NMR spectrum of isolated amine **2a** (Table ESI 1 entry 2).

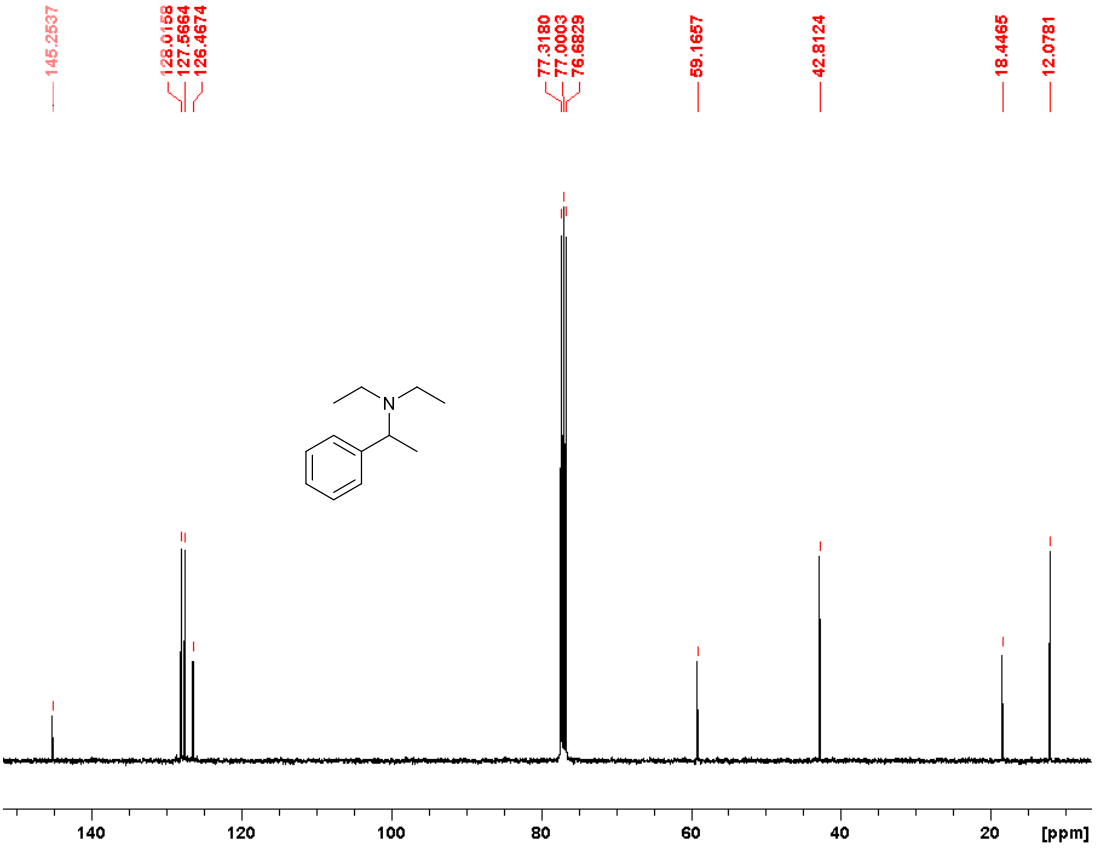

Figure ESI 10. [13]C NMR spectrum of isolated amine **2a** (Table ESI 1 entry 2).

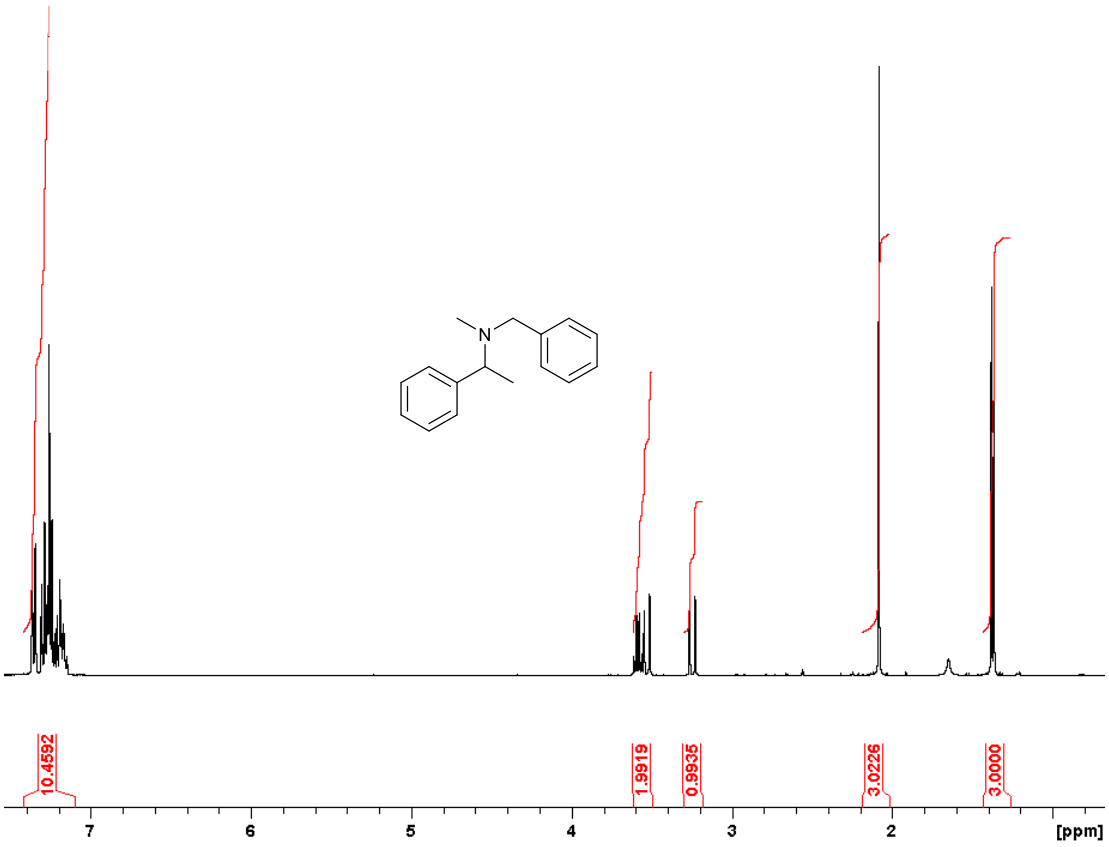

Figure ESI 11. ^{1}H NMR spectrum of isolated amine **2b** (Table ESI 1 entry 6).

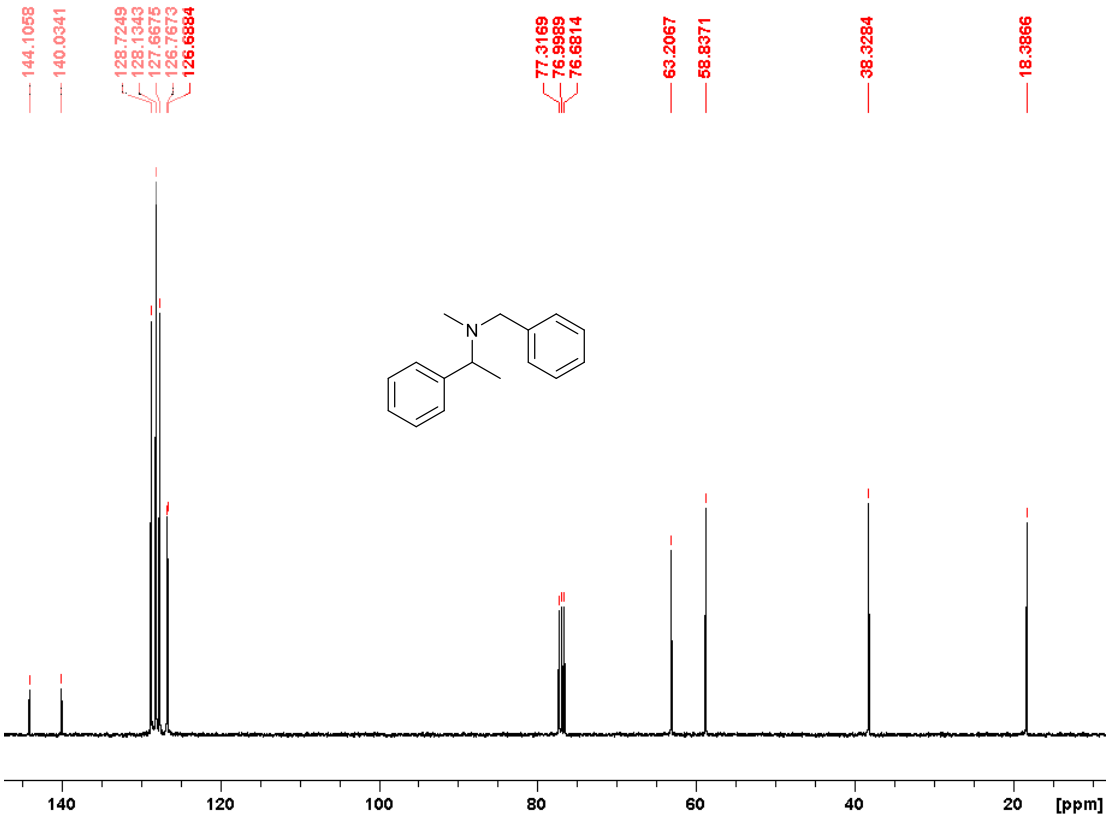

Figure ESI 12. ^{13}C NMR spectrum of isolated amine **2b** (Table ESI 1 entry 6).