Supporting Information

Palladium Complexes Derived from Waste as Catalysts for C-H Functionalisation and C-N Bond Formation

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S1 Synthetic procedures

S1.1 General synthetic procedures

All of the chemicals and reagents were acquired and used without subsequent purification unless otherwise stated. The synthesis of compounds and catalysis experiments were conducted in an ambient environment unless otherwise specified. The compounds obtained were stable in air at room temperature. Infra-red spectra were recorded on the Perkin Elmer Spectrum 100-FT-IR Spectrometer with 16 scans of 600 to 4000 cm^{-1} on solid samples. ^{1}H NMR, $^{31}P\{^{1}H\}$ NMR and $^{13}C\{^{1}H\}$ NMR analyses were performed at 25 °C using Varian Bruker AV400 spectrometers in deuterated $CDCl_3$ unless stated otherwise. Chemical shifts and coupling constants in NMR spectra were reported in part per million (ppm) and Hertz (Hz), respectively. Elemental analysis measurements were conducted at London Metropolitan University. A Micromass Autospec and Waters LCT Premier ES-ToF was employed to gather mass spectrometry data (ES and MALDI-TOF). HPLC analyses were performed on a PerkinElmer Series 200 HPLC fitted with a Supercosil LC18 (25 cm x 4.6 mm x 5 µm) and a Series 200 EP Diode Array UV-Vis detector measuring at 254 and 238 nm, and the data were analysed in TotalChrom. TEM data were recorded using a JEOL 2010 high-resolution TEM (80-200 kV) equipped with an Oxford Instruments INCA EDS 80 mm X-Max detector system. The DoE optimisation was conducted in JMP Pro 16. The processes described provide pure materials for synthetic and spectroscopic uses.

*S1.2 Synthesis and data for $[N^nBu_4]_2[Pd_2I_6]$ (**1**)*

Following the literature method,[S1] palladium metal powder (20.7 mg, 0.20 mmol) was added to an acetone solution (30 mL) of $[N^nBu_4]I$ (72 mg, 0.20 mmol) and I_2 (51 mg, 0.20 mmol) and the reaction mixture was stirred at room temperature for 3 hours. The initial brown solution slowly became darker as the reaction proceeded, followed by the precipitation of a black crystalline product. The precipitate was filtered and washed with cold acetone, with a further crop of black crystalline product being obtained by layering the filtrate with Et_2O. Combined yield: 126 mg (86%). IR: 2960, 2869, 1457, 1379, 1176, 1108, 1067, 1030, 881, 802, 740 cm^{-1}. MS (ES -ve) *m/z* (abundance %): 487 (100) $[PdI_3]^-$. UV−Vis λ in MeCN (ε, $dm^3\ mol^{-1}\ cm^{-1}$): 340 (38096), 450 (7492), 549 (5324) nm. Anal. Calcd (%) for $C_{32}H_{72}N_2I_6Pd_2$: C 26.3, H 5.0, N 1.9. Found (%): C 26.1, H 4.8, N 1.9. Data were found to agree well with those reported previously for this complex.[S1]

A slight modification was made to reduce the synthesis time by adding the ethanol (20 mL) into a reaction mixture after 3 h. The solvent was concentrated using a rotary evaporator, and the product was precipitated as a black powder (less crystalline than the above method) from the remaining ethanol solution with 87% yield. This was filtered and washed with cold acetone. The spectroscopic data agreed well with those obtained using the previous workup procedure.

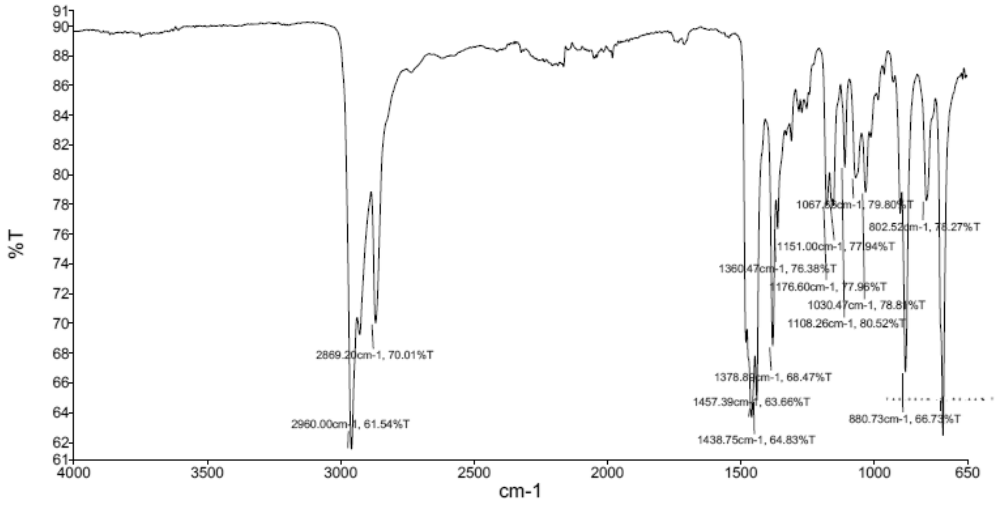

Figure S1-1. Solid-state infrared spectrum of $[N^nBu_4]_2[Pd_2I_6]$ (**1**).

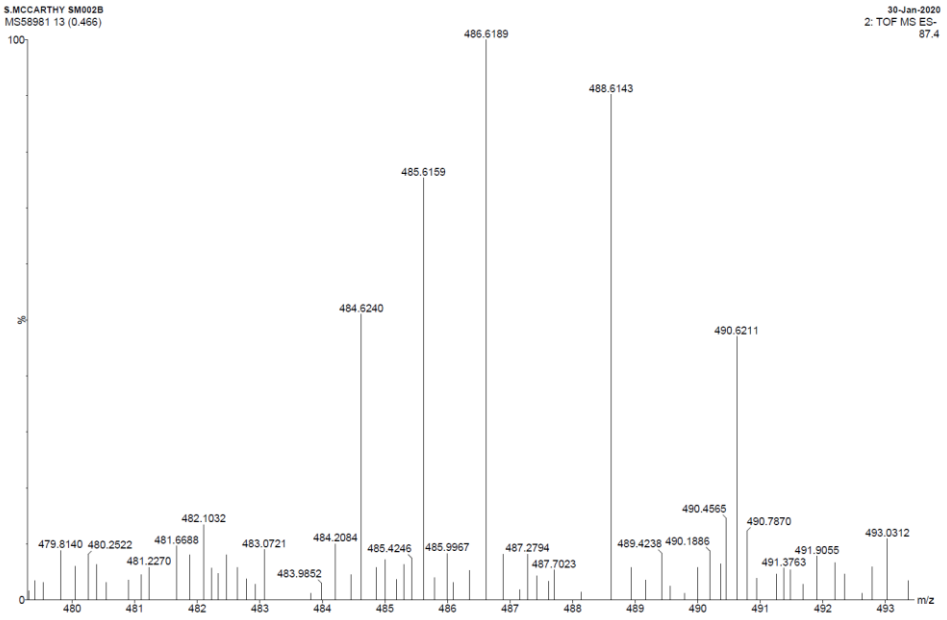

Figure S1-2. Mass spectrum of $[N^nBu_4]_2[Pd_2I_6]$ (**1**).

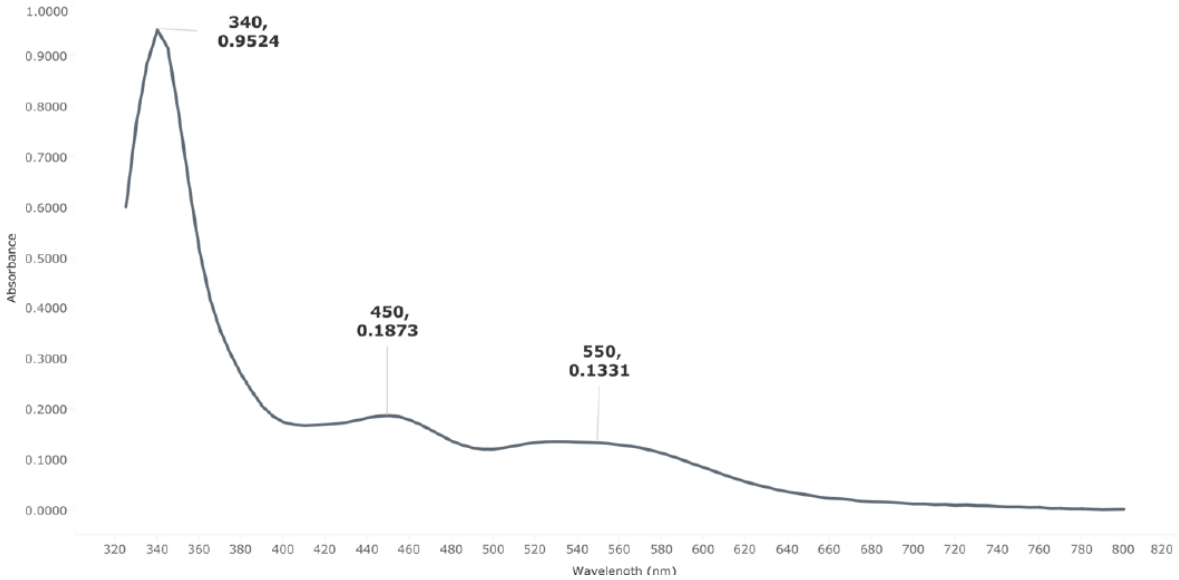

Figure S1-3. UV-Vis spectrum of $[N^nBu_4]_2[Pd_2I_6]$ (**1**) in MeCN.

*S1.3 Synthesis and data for $[PdI_2(dppf)]$ (**2**)*

$[N^nBu_4]_2[Pd_2I_6]$ (**1**) (365 mg, 0.25 mmol) was dissolved in acetone (10 mL) and stirred at room temperature for 10 minutes. An acetone solution (25 mL) of dppf (277 mg, 0.50 mmol) was added dropwise into the black reaction mixture. The reaction mixture slowly became a brown solution, which was stirred for 3 hours, leading to the formation of a precipitate. The product was filtered and washed with ethanol (15 mL) and diethyl ether (15 mL). The product was then dried under a vacuum to give a brown solid (442 mg, 97%). IR: 1714, 1480, 1434, 1359, 1302, 1217, 1167, 1092, 1101, 1040, 999, 819, 745, 698 cm^{-1}. ^1H NMR: δ 4.14 (s(br), 4H, C_5H_4), 4.35 (s(br), 4H, C_5H_4), 7.37 – 7.48 (m, 12H, Ph), 7.84 – 7.89 (m, 8H, Ph) ppm. $^{31}P\{^1H\}$ NMR: δ 24.3 (s, dppf) ppm. MS (ES +ve) *m/z* (abundance): 937 (6) $[M + Na]^+$, 787 (100) $[M-I]^+$. Anal. Calcd (%) for $C_{34}H_{28}FeI_2P_2Pd \cdot 0.5CH_2Cl_2$: C 43.3, H 3.1. Found (%): C 43.1, H 2.8. Data were found to agree well with those reported previously for this complex.[S2]

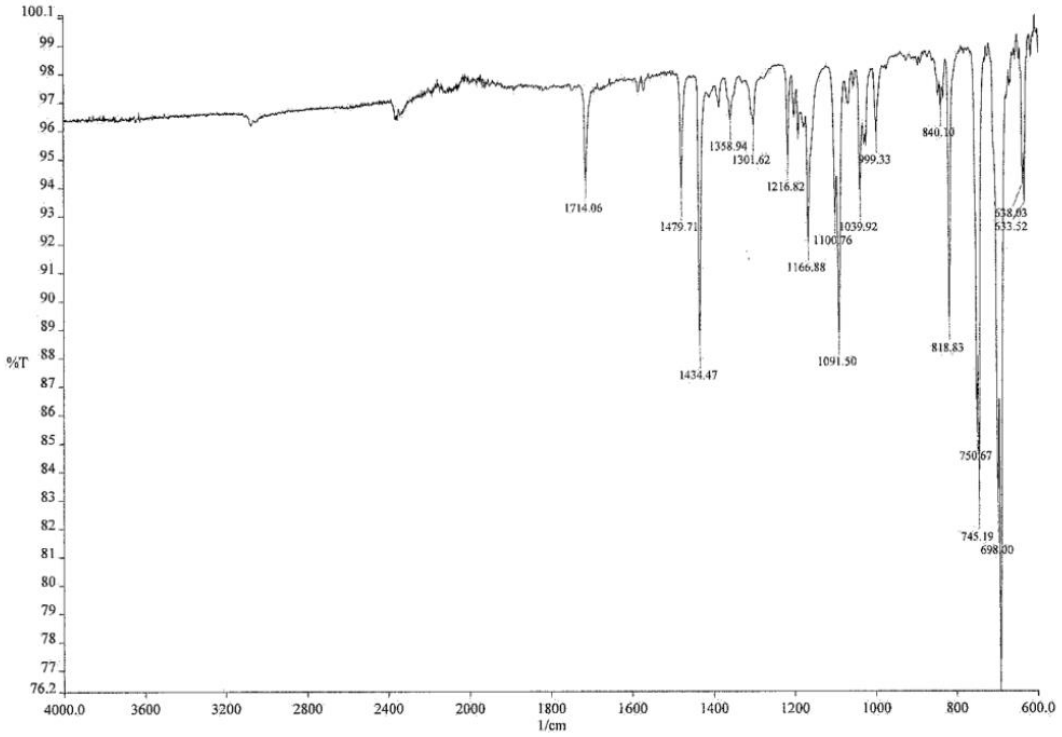

Figure S1-4. Solid-state infrared spectrum for [PdI_2(dppf)] (**2**).

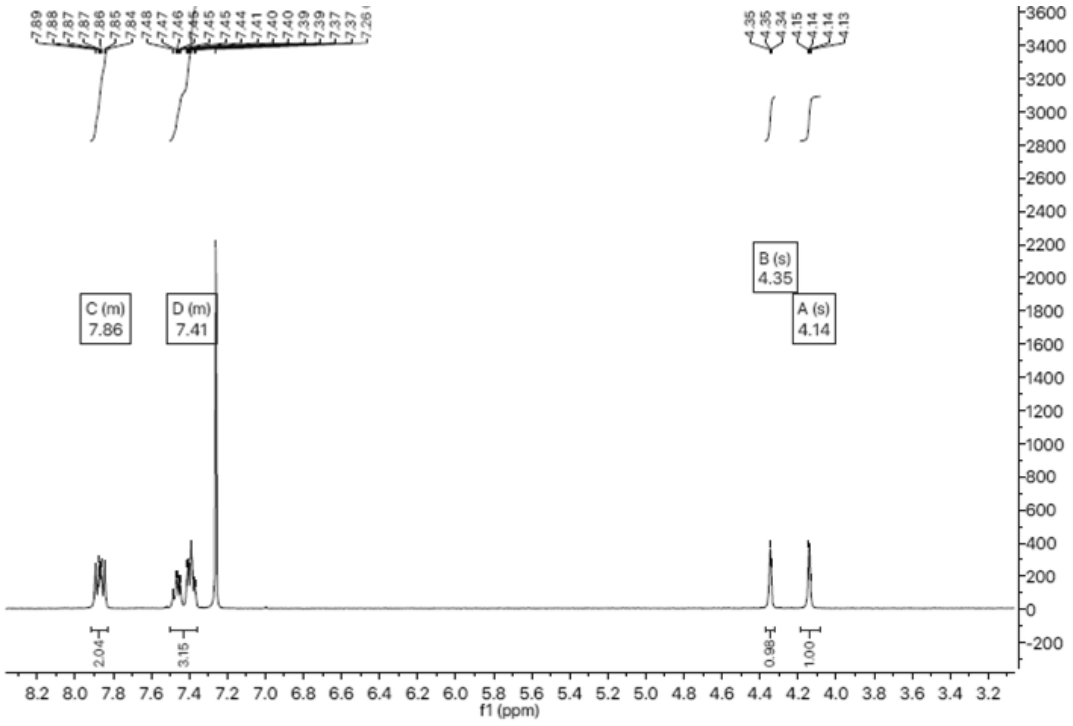

Figure S1-5. ^{1}H NMR spectrum of [PdI_2(dppf)] (**2**) in $CDCl_3$.

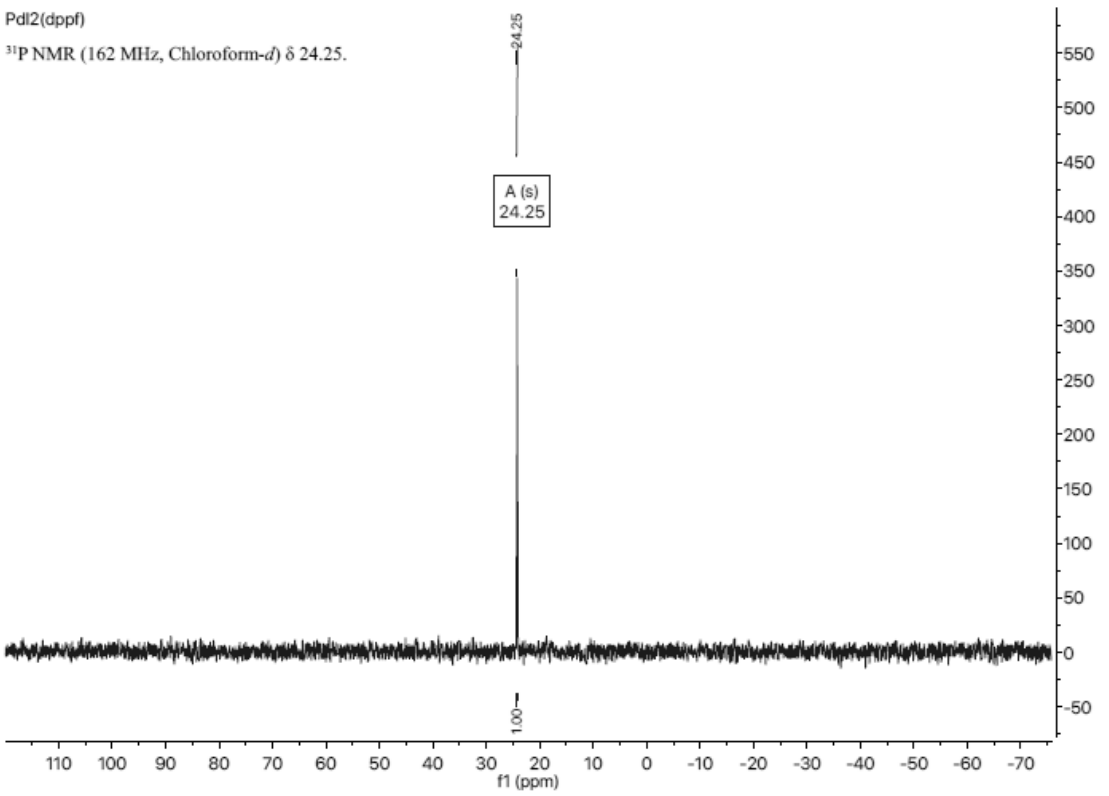

Figure S1-6. $^{31}P\{^{1}H\}$ NMR spectrum of [PdI_2(dppf)] (**2**) in $CDCl_3$.

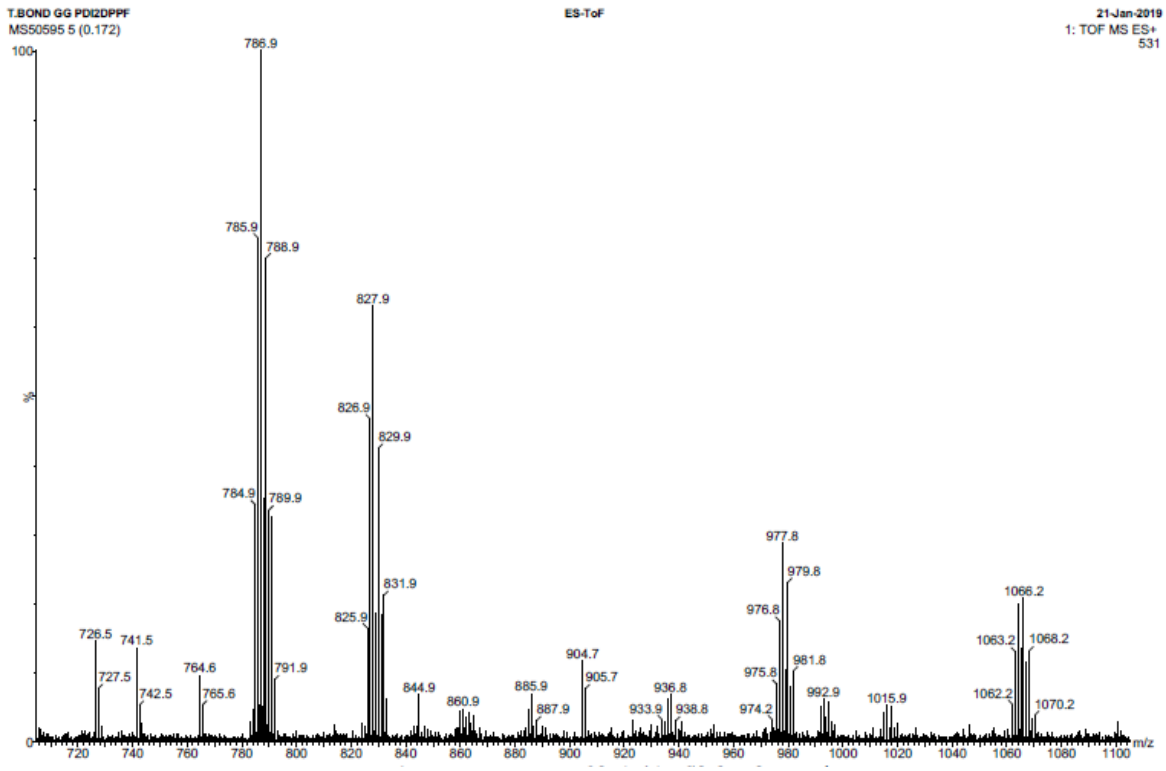

Figure S1-7. Mass spectrum of [PdI_2(dppf)] (**2**).

S2 X-ray crystallography

S2.1 The X-ray crystal structure of Pd_2(dppf) (2)

Crystal data *for* **2**: $C_{34}H_{28}FeI_2P_2Pd \cdot C_2H_6O$, M = 960.62, triclinic, P-1 (no. 2), a = 9.9345(3), b = 10.6355(4), c = 17.5846(6) Å, α = 86.238(3), β = 75.795(3), γ = 67.545(3)°, V = 1663.75(11) Å^3, Z = 2, D_c = 1.918 g cm^{-3}, μ(Mo-Kα) = 2.957 mm^{-1}, T = 173 K, brown plates, Agilent Xcalibur 3 E diffractometer; 6559 independent measured reflections (R_{int} = 0.0294), F^2 refinement,[S3-5] R_1(obs) = 0.0388, wR_2(all) = 0.0740, 5041 independent observed absorption-corrected reflections [$|F_o| > 4\sigma(|F_o|)$, completeness to θ_{full}(25.2°) = 98.6%], 361 parameters. CCDC 2336801.

The included solvent was found to be highly disordered, and the best approach to handling this diffuse electron density was found to be the SQUEEZE routine of PLATON.[S6] This suggested a total of 58 electrons per unit cell, equivalent to 29 electrons per complex. With the refinements from before the use of SQUEEZE giving no clear indication as to the identity of the solvent, the most recently used solvent (ethanol, C_2H_6O, 26 electrons) was assumed, with one ethanol molecule corresponding to 26 electrons, so this was used as the solvent present. As a result, the atom list for the asymmetric unit is low using C_2H_6O (and that for the unit cell low using $C_4H_{12}O_2$) compared to what is actually presumed to be present. Although this is a higher quality dataset, this structure is essentially the same as that previously reported by Colacot et al.[S2]

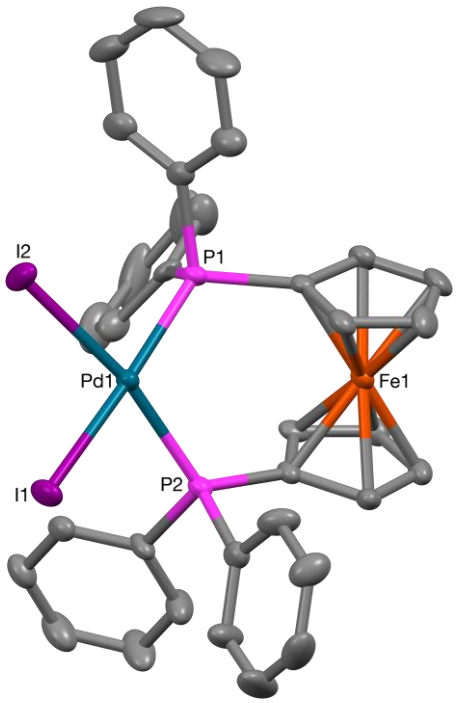

Figure S2-1. The crystal structure of **2** (50% probability ellipsoids).

S3 General conditions for catalysis

S3.1 General catalytic procedure

A drysyn multiwell heating block was filled with standard 14 mL thin-walled and thick-walled vials for the catalytic procedure, which was carried out at 50 °C and 100 °C, respectively. The stirrer hotplate was connected to an electronic contact thermometer controlling the temperature. The temperature was allowed to rise before the vials were inserted. Effective heat transfer between the block and the vials was ensured using silicone oil in the wells.

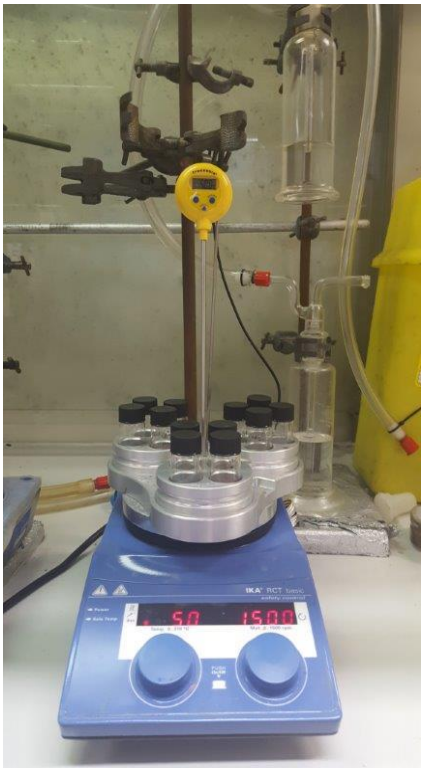

Figure S3-1. Reaction setup for catalytic reactions.

S3.2 C-H Functionalisation reactions

S3.2.1 Synthesis of 10-alkoxybenzo[h]quinolines

Benzo[*h*]quinoline (50.0 mg, 0.28 mmol), (diacetoxyiodo)benzene (180.4 mg, 0.56 mmol) and the selected catalyst (loadings between 1 and 2 mol%) were combined in 2.5 mL of the alcohol, ROH (R = Me, Et, Pr^i, CH_2CF_3), and stirred using a magnetic stir bar at 50 °C or 100 °C for a set time (0.2-24 hours). The solvent was removed (rotary evaporation) followed by the dissolution of the residue in $CDCl_3$. The rate of conversion to the product was measured by means of the integration of the diagnostic resonances in the ^1H NMR spectra for the H-2 (9.27 ppm) and H-10 protons (9.03 ppm) of benzo[*h*]quinoline with those of the alkoxy group in the product (see Figure S3-2), which appeared at 4.19 ppm (methoxy, CH_3), 1.63 and 4.45 ppm (ethoxy, CH_2CH_3), 1.54 and 4.76 ppm (isopropoxy, $CH(CH_3)_2$), and 4.74 ppm (trifluoroethoxy, CH_2CF_3). Isopropanol (1.25 mL) and glacial acetic acid (1.25 mL) were used in the preparation of 10-isopropoxybenzo[*h*]quinoline.

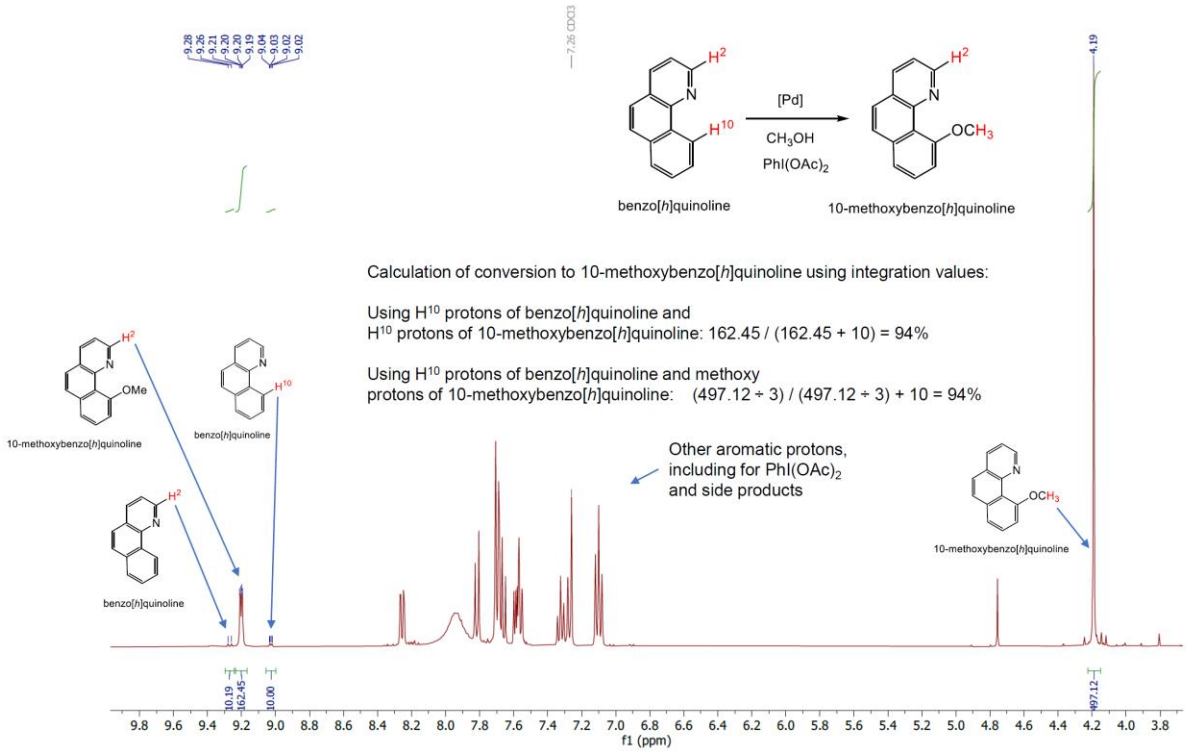

Figure S3-2. ^{1}H NMR spectrum in the $CDCl_3$ of the reaction mixture after the formation of 10-methoxybenzo[*h*]quinoline from benzo[*h*]quinoline showing the calculation of the conversion rate using the integration of the proton environments in the starting material and the product.

An isolated yield for 10-methoxybenzo[*h*]quinoline was obtained by heating benzo[*h*]quinoline (150 mg) and 2 mol% of **1** in methanol (7.5 mL) at 50 °C for 2 hours. After the removal of the solvent (rotary evaporation), the resulting oil was dissolved in ethyl acetate and a flash column was used (eluent 3:2 v/v ethyl acetate to *n*-hexane) to provide the desired product as a pale-yellow solid (169.9 mg, 97%). Spectroscopic data and analytical data were found to be in good agreement with those reported in the literature.[S7] ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.13 (dd, *J* = 4.4, 2.0 Hz, 1H), 8.17 (dd, *J* = 8.0, 1.9 Hz, 1H), 7.79 (d, *J* = 8.8 Hz, 1H), 7.67 (d, *J* = 8.8 Hz, 1H), 7.64 (t, *J* = 7.9 Hz, 1H), 7.55 (dd, *J* = 7.9, 1.3 Hz, 1H), 7.50 (dd, *J* = 8.0, 4.4 Hz, 1H), 7.26 (dd, *J* = 8.0, 1.0 Hz, 1H), 4.19 (s, 3H) ppm.

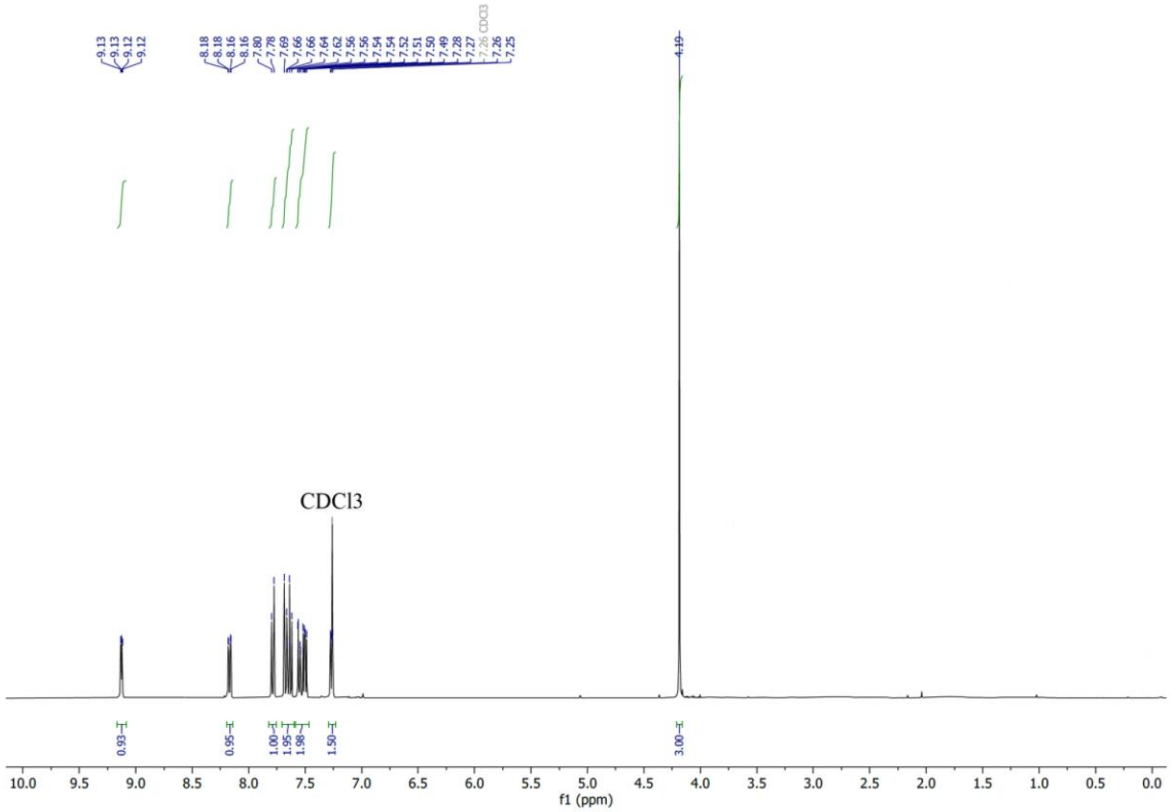

Figure S3-3. ^{1}H NMR spectrum in $CDCl_3$ of isolated 10-methoxybenzo[*h*]quinoline.

Characterisation of the other compounds was in agreement with previous literature data.[S7]

10-ethoxybenzo[*h*]quinoline: ^{1}H NMR ($CDCl_3$): δ 9.11 (dd, *J* = 4.0 Hz, 2.0 Hz, 1H), 8.15 (dd, *J* = 8.0 Hz, 2.0 Hz, 1H), 7.77 (d, *J* = 9.0 Hz, 1H), 7.65 (d, *J* = 9.0 Hz, 1H), 7.61 (t, *J* = 8.0 Hz, 1H), 7.56 (dd, *J* = 8.0 Hz, 1.0 Hz, 1H), 7.49 (dd, *J* = 8.0 Hz, 4.5 Hz, 1H), 7.29 (dd, *J* = 8.0 Hz, 1.0 Hz, 1H), 4.36 (q, *J* = 7.0 Hz, 2H), 1.67 (t, *J* = 7.0 Hz, 3H).

10-isopropoxybenzo[*h*]quinoline: ^{1}H NMR ($CDCl_3$): δ 9.09 (dd, *J* = 4.5 Hz, 2.0 Hz, 1H), 8.11 (dd, *J* = 8.0 Hz, 2.0 Hz, 1H), 7.76 (d, *J* = 9.0 Hz, 1H), 7.62-7.57 (m, 3H), 7.46 (dd, *J* = 8.0 Hz, 4.5 Hz, 1H), 7.34 (dd, *J* = 6.5 Hz, 3.0 Hz, 1H), 4.64 (septet, *J* = 6.0 Hz, 1H), 1.50 (d, *J* = 6.0 Hz, 6H) ppm.

10-trifluoroethoxybenzo[*h*]quinoline: δ 9.09 (dd, *J* = 4.5 Hz, 2.0 Hz, 1H), 8.18 (dd, *J* = 8.0 Hz, 2.0Hz, 1H), 7.81 (d, *J* = 8.5 Hz, 1H), 7.75 (dd, *J* = 7.5 Hz, 1.0 Hz, 1H), 7.69 (d, *J* = 9.0 Hz, 1H), 7.63 (t, *J* = 8.0 Hz, 1H), 7.53 (dd, *J* = 8.0 Hz, 4.5 Hz, 1H), 7.50 (d, *J* = 8.0 Hz, 1H), 4.66 (q, *J* = 9.0 Hz, 2H) ppm.

Reaction profile analysis was carried out using benzo[*h*]quinoline (50.0 mg, 0.28 mmol), (diacetoxy-iodo)benzene (180.4 mg, 0.56 mmol) and $Pd(OAc)_2$ (1.1 mol%) in methanol (2.5 mL) and heated at 100 °C for the designated time (0.2, 0.4, 1, 2, 5, and 22 h). The solvent was removed under reduced pressure, and ^{1}H NMR spectroscopy was used to analyse the conversion via the integration of the resonances indicated above.

In control experiment **A**, benzo[*h*]quinoline (50.0 mg, 0.28 mmol) was treated with **1** (1.0 mol% [Pd]) or $Pd(OAc)_2$ (1.1 mol% [Pd]) in methanol at 100 °C. In control experiment **B**, (diacetoxyiodo)benzene (180.4 mg, 0.56 mmol) and **1** (1.0 mol% [Pd]) or $Pd(OAc)_2$ (1.1 mol% [Pd]) were treated in methanol at 100 °C. In control experiment **C**, compound **1** (1.0 mol% [Pd]) or $Pd(OAc)_2$ (1.1 mol% [Pd]) was heated in methanol at 100 °C for 2 or 22 h, respectively. TEM was used to analyse the black precipitate.

In an experiment to assess the impact of PdNP formation on the oxidative C-H functionalisation reaction, $Pd(OAc)_2$ (1.1 mol%) was added to methanol (2.5 mL) and heated at 100 °C for 2 h. Then, benzo[*h*]quinoline (50.0 mg, 0.28 mmol) and (diacetoxyiodo)benzene (180.4 mg, 0.56 mmol) were added, and the reaction mixture was stirred for another 1, 2, 5 or 22 h. The solvent was removed under reduced pressure, and ^{1}H NMR spectroscopy was used to analyse the resultant crude.

S3.2.2 Synthesis of 8-(methoxymethyl)quinoline

In a typical experiment, 8-methylquinoline (42.5 mg, 0.297 mmol), (diacetoxy-iodo)benzene (103.3 mg, 0.321 mmol) and the selected catalyst (loadings between 1 to 2 mol%) were combined in methanol (2.5 mL) and stirred using a magnetic stir bar at 50 °C or 100 °C for a set time (2 - 24 hours). All of the solvent was then removed (rotary evaporation) followed by dissolution of the residue in $CDCl_3$. The integration of the diagnostic resonances in the ^{1}H NMR spectra for the CH_3 (2.82 ppm) resonance of 8-methylquinoline was compared with those of the methylene group (5.19 ppm) and methoxy group (3.57 ppm) in the 8-(methoxymethyl)quinoline product.

An isolated yield was obtained by carrying out the reaction on a larger scale with 8-methylquinoline (127.5 mg, 0.89 mmol), (diacetoxyiodo)benzene (309.9 mg, 0.96 mmol) and 1 mol% of **1** in methanol (7.5 mL) at 50 °C for 2 hours. A flash column was used (eluent 3:2 v/v ethyl acetate to *n*-hexane) to provide the desired product as a pale-yellow solid (145.20 mg, 94%). Spectroscopic data and analytical data were found to be in good agreement with those reported in the literature.[S7] ^{1}H NMR ($CDCl_3$): δ 8.94 (dd, *J* = 4.4 Hz, 2.0 Hz, 1H), 8.15 (dd, *J* = 8.2 Hz, 1.8 Hz, 1H), 7.82 (dd, *J* = 7.0 Hz, 1.0 Hz, 1H), 7.75 (d, *J* = 8 Hz, 1H), 7.56 (t, *J* = 7.8 Hz, 1H), 7.42 (dd, *J* = 8.2 Hz, 4.2 Hz, 1H), 5.20 (s, 2H), 3.58 (s, 3H) ppm.

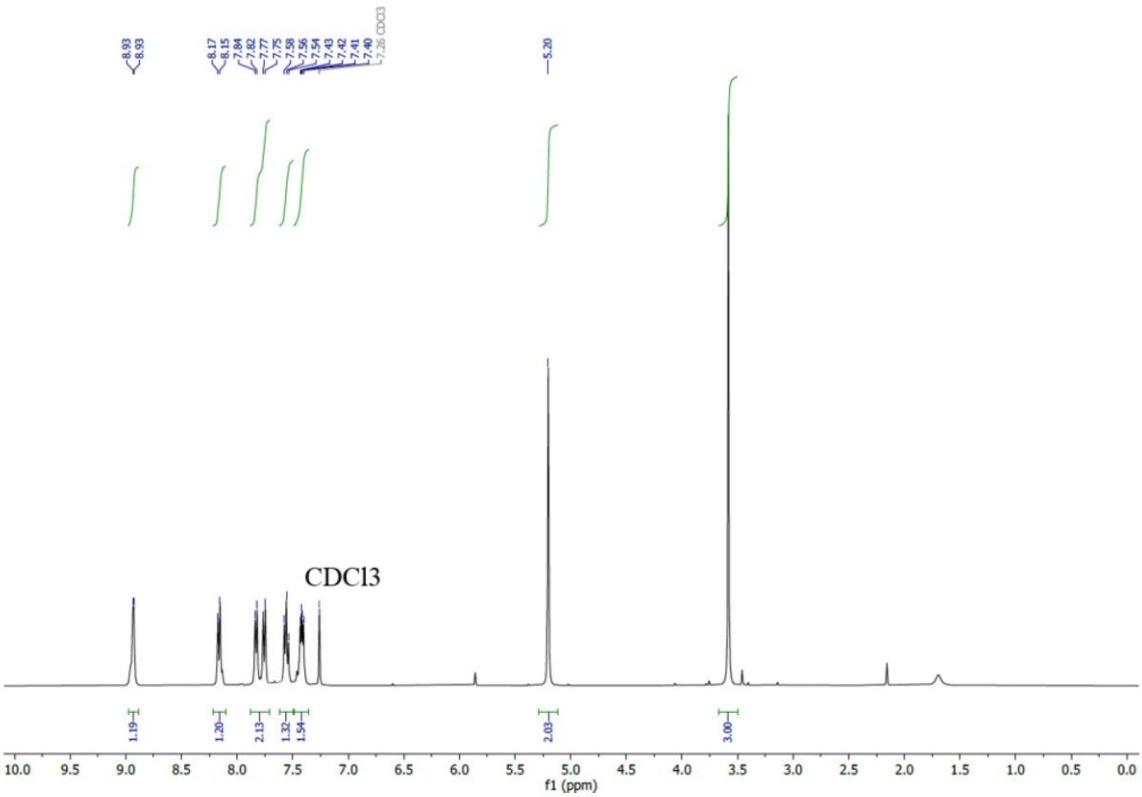

Figure S3-4. ^{1}H NMR spectrum in $CDCl_3$ of isolated 8-(methoxymethyl)quinoline.

S3.2.3 Recovery and re-use experiments

Benzo[*h*]quinoline (500 mg, 2.79 mmol), (diacetoxyiodo)benzene (1.804 g, 5.589 mmol), 1,3,5- trimethoxybenzene (156 mg, 0.930 mmol) and $[N^{n}Bu_4]_2[Pd_2I_6]$ (**1**, 81.4 mg, 0.0558 mmol, 2 mol%) were stirred in ethanol (5 mL) at 75 °C for 2 h. The reaction mixture was filtered, the black solids washed with ethanol (5 mL) and the filtrate was concentrated under vacuum. The resulting crude residue was dissolved in $CDCl_3$ for analysis. Conversion to the desired product was determined via the integration of the diagnostic environments in the ^{1}H NMR spectrum ($CDCl_3$) for the product (1.63 ppm, CH_2CH_3; 4.45 ppm, CH_2CH_3) with comparison to the internal standard (trimethoxybenzene, 3.75 ppm, CH_3). The black solid collected by means of filtration was dried under vacuum and added to a stirred solution of tetra-n-butylammonium iodide (41.4 mg, 0.112 mmol), I_2 (28.4 mg, 0.112 mmol) in acetone (15 mL) at room temperature. After 24 h, the solution was filtered under gravity, concentrated to ~5 mL and the product was obtained by means of vapour diffusion with Et_2O. The resulting crystals were filtered and dried, yielding **1** as a shiny black crystalline solid (61 mg, 75%). M.p. 182.3-183.1 °C. UV–vis (nm): 340, 451, 542. The recovered sample of **1** was used in a second C-H activation of benzo[*h*]quinoline in ethanol.

S3.3 Amination reactions

These catalysis experiments used 8 mL of the solvent (THF, CPME or toluene), and all reactions were performed at least three times. Integration of the diagnostic resonances in the ^{1}H NMR spectra for the methyl resonances of the *N*-(*p*-tolyl)-[1,1'-biphenyl]-4-amine product

(2.33 ppm) with those for *p*-toluidine (2.24 ppm) was used to determine the conversion, taking into account the excess of *p*-toluidine used. The substantially higher boiling point of *p*-toluidine (200 °C) than the solvents (THF = 66 °C, CPME = 106 °C, toluene = 111 °C) allowed the latter to be removed via rotary evaporation without the removal of the former. This method was compared to the use of 1,3,5-trimethoxybenzene as an internal standard and found to be accurate within 2-5%, obviating the need for routine use of an internal standard.

The characterisation data for the following compounds were found to agree well with those reported in the literature: 4-methyl-4'-phenyldiphenylamine,[S8] 4-methoxy-N-(4-methylphenyl)benzenamine,[S9] 4-methyl-*N*-(4-methylphenyl)benzenamine,[S10] 4-[(4-methylphenyl)amino]benzaldehyde,[S11] 4-methyl-N-(4-nitrophenyl)aniline,[S11] *N*-(3-methylphenyl)[1,1′-biphenyl]-4-amine,[S12] *N*-(2-methylphenyl)[1,1′-biphenyl]-4-amine.[S12]

S3.3.1 Solvent optimisation

Para-bromobiphenyl (233.1 mg, 1.00 mmol), *p*-toluidine (128.6 mg, 1.20 mmol), sodium *t*-butoxide (115.3 mg, 1.20 mmol), dppf (15 mol%) and the catalyst (5 mol%) were combined in 8 mL of the solvent (THF, toluene or CPME) and stirred at 100 °C for 3 hours. All of the solvent was then removed (rotary evaporation), followed by dissolution of the residue in $CDCl_3$. The rate of conversion to the desired product was determined using ^{1}H NMR spectroscopy as described above.

S3.3.2 The benchmark reaction without addition of dppf

Para-bromobiphenyl (233.1 mg, 1.00 mmol), *p*-toluidine (128.6 mg, 1.20 mmol), sodium *t*-butoxide (115.3 mg, 1.20 mmol) and catalyst **2** (5 mol%) were combined in CPME (8 mL) and stirred at 100 °C for 3 hours. All of the solvent was then removed (rotary evaporation), followed by dissolution of the residue in $CDCl_3$. The conversion to the desired product was determined using ^{1}H NMR spectroscopy as described above.

*S3.3.3 Reaction using the in situ generation of PdI_2(dppf) (**2**)*

Para-bromobiphenyl (233.1 mg, 1.00 mmol), *p*-toluidine (128.6 mg, 1.20 mmol), sodium *t*-butoxide (115.3 mg, 1.20 mmol), dppf (111 mg, 20 mol%) and catalyst **1** (36.5 mg, 5 mol% [Pd]) were combined in CPME (8 mL) to give a 1:3 ratio of [**2**]:[dppf]. The reaction was stirred at 100 °C for 3 hours. All of the solvent was then removed (rotary evaporation), followed by dissolution of the residue in $CDCl_3$. The conversion to the desired product was determined using ^{1}H NMR spectroscopy as described above.

S3.3.4 HPLC monitoring reaction setup

HPLC calibration curves were constructed from a series of solutions containing 4-bromobiphenyl (59.9 mg), (*N*-(*p*-tolyl)-[1,1'-biphenyl]-4-amine (66.6 mg) and an internal standard (naphthalene) (43.9 mg) at different concentration ratios. Calibration solutions were prepared by diluting stock solutions with MeCN to obtain concentration ratios of 0.125, 0.5, 0.875, 1.25, 1.625 and 2.0 for each analyte. HPLC determination was carried out with a

PerkinElmer Series 200 HPLC fitted with a Supercosil LC18 column (25 cm x 4.6 mm x 5 µm) and a Series 200 EP Diode Array UV-Vis detector measuring at 254 and 238 nm, and the data were analysed in Total-Chrom.

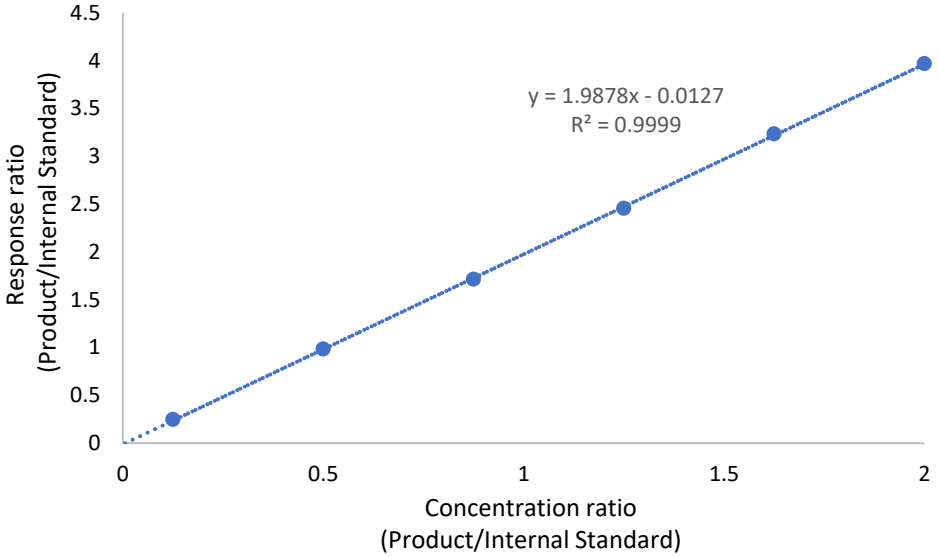

Figure S3-5. HPLC calibration curve of the product against the 1,3,5-trimethoxybenzene internal standard.

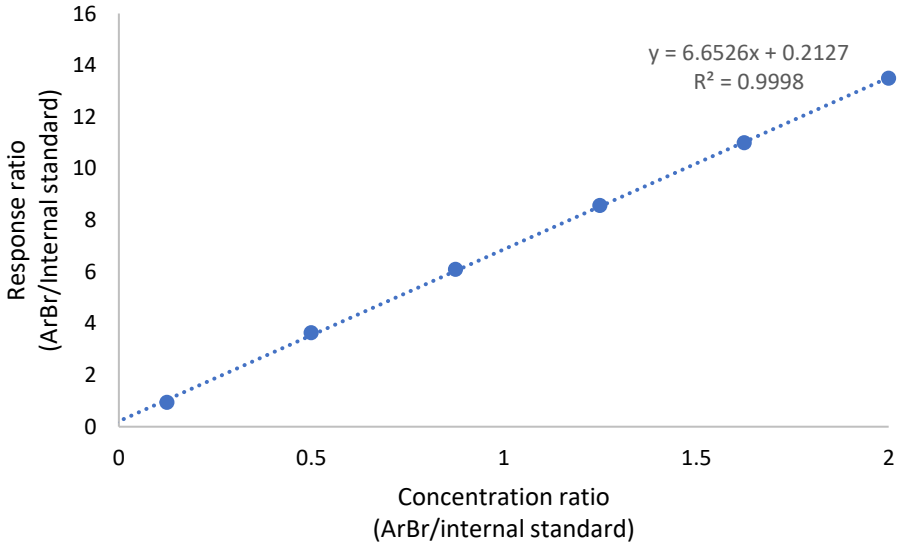

Figure S3-6. HPLC calibration curve of *p*-bromobiphenyl against the 1,3,5-trimethoxybenzene internal standard.

S3.3.5 Design of Experiment (DoE) optimisation

An appropriate stock solution (250 mL) containing *p*-bromobiphenyl (7.2844 g), *p*-toluidine (4.0181 g) and naphthalene (2.0027 g) in CPME was used for the DoE screening. In this process, 8 mL of stock solution was transferred into a ReactArray multireaction chamber instrument followed by appropriate quantities of sodium *t*-butoxide (115.3 mg) and dppf (3-15

mol %). The vial was fitted with a cold-finger condenser and stirred at 100 °C for 10 minutes. Catalyst **2** (1-5 mol%) was introduced to initiate the reaction, and the reaction was stirred at 100 °C for a designated time frame (30-120 min). After reaching the time indicated, an aliquot (~2 µL) of the reaction solution was diluted in MeCN (~5 mL) and submitted for HPLC analysis. The data (Table S5-1) were exported to Excel for processing.

In the procedure used for the Design of Experiments (DoE) study, a stock solution containing *p*-bromobiphenyl, *p*-toluidine and naphthalene was used for the DoE screening. In this process, 8 mL of stock solution were transferred to the vials followed by appropriate quantities of sodium *t*-butoxide and dppf. PdI_2(dppf) (**2**) was introduced to initiate the reaction followed by stirring at 100 °C.

Table S3-1. Definitive screening design parameters used in the Design of Experiments (DoE) model for the reaction of p-bromobiphenyl and p-toluidine at 100 °C in CPME solution.

Factor	Lower limit	Upper limit
Catalyst loading (mol%)	1	5
dppf loading (mol%)	3	15
Time (min)	30	120

Table S3-2. Terms included in the definitive screening design model and their corresponding LogWorth values with larger values indicate a larger influence on the model. Terms with a LogWorth < 2 are not statistically significant and are not included.

Model Term	LogWorth
Time	6.776
Catalyst loading*time	4.602
Catalyst loading*dppf loading	4.243
dppf loading	4.208
Catalyst loading	4.200
Time*time	2.050

S3.3.6 Kinetic studies

Para-bromobiphenyl (233.1 mg, 1.00 mmol), *p*-toluidine (128.6 mg, 1.20 mmol), sodium *t*-butoxide (115.3 mg, 1.20 mmol), dppf (3 mol%) and 1,3,5 trimethoxybenzene were combined in CPME (8 mL) and transferred to the ReactArray. The vial was fitted with a cold-finger condenser and stirred just below the boiling point of the solvent at 100 °C for 10 minutes. Catalyst **2** (1 mol%) was introduced to initiate the reaction, and the reaction was stirred at 100 °C for the designated time (0-180 min). After reaching the time indicated, an aliquot (~0.1 mL) of the reaction solution was removed and quenched with a mixture of deuterated chloroform and acetic acid. The solution was filtered with Celite and submitted for ^{1}H NMR analysis. The integration of the methyl peak of the internal standard (3.77 ppm) was compared with the methyl resonance of the product (2.33 ppm).

S3.3.7 Investigation of substrate scope

The aryl bromide [1.0 mmol; *p*-bromobiphenyl (233.1 mg), *p*-bromoanisole (125.2 µL), *p*-bromotoluene (171.0 mg), *p*-bromobenzaldehyde (185.2 mg), 1-bromo-4-nitrobenzene (202.0 mg)] and the arylamine [1.2 mmol; *p*-toluidine (128.6 mg), *m*-toluidine (128.6 µL), *o*-toluidine (128.8 µL)] were dissolved in CPME (8 mL) along with the catalyst (1 or 2 mol%), dppf (3 – 15 mol%), and sodium *t*-butoxide (115.3 mg, 1.2 mmol). The solution was stirred at 100 °C for 3 hours. The conversion to the desired product was determined via the integration of the ^{1}H NMR spectrum as follows. For the reaction of aryl bromide with *p*-toluidine, the conversion was determined by comparing the integrals of the methyl resonance in *p*-toluidine (2.24 ppm) with the integral of the same feature in the relevant product [*p*-bromobiphenyl (2.33 ppm), *p*-bromoanisole (2.30 ppm), *p*-bromotoluene (2.29 ppm), *p*-bromobenzaldehyde (2.34 ppm), 1-bromo-4-nitrobenzene (2.36 ppm)]. For the reaction of *p*-bromobiphenyl with *m*-toluidine and *o*-toluidine, the conversion to the desired product was determined by comparing the integrals of the methyl resonance in *m*-toluidine (2.27 ppm) and *o*-toluidine (2.23 ppm) with the integrals of the methyl resonances in the desired products (2.33 ppm). An internal standard, 1,3,5-trimethoxybenzene, was also used to improve accuracy. The initial excess of *p*-toluidine, *m*-toluidine and *o*-toluidine was taken into account.

S4 Data for C-H oxidative functionalisation reactions

The data shown in graphs in the main text and additional supplementary data not reported in full in the main text are presented in table form below.

Table S4-1. Reaction profile for the conversion of benzo[*h*]quinoline to 10-methoxybenzo[*h*]quinoline with $Pd(OAc)_2$ (1.1 mol%) in the presence of 2 equivalents of $PhI(OAc)_2$ in MeOH at 50 °C and 100 °C. The rate of conversion to the desired product was determined by ^1H NMR spectroscopy as an average of three independent experiments.

Temperature (°C)	Solvent	Loading	t (h)	Conversion (%)
100	MeOH	1.1% [Pd]	0.2	88 ± 2
			0.4	93 ± 1
			1	94 ± 1
			2	95 ± 1
			5	95 ± 3
			22	96 ± 1
50	MeOH	1.1% [Pd]	0.2	34 ± 1
			0.4	45 ± 1
			1	54 ± 2
			2	70 ± 2
			5	86 ± 1
			22	95 ± 1

Table S4-2. Transformation of benzo[*h*]quinoline to 10-alkoxybenzo[*h*]quinoline catalysed by **1** in different solvents at 100 °C using 2 equivalents of $PhI(OAc)_2$. The rate of conversion to the desired product was determined by ^1H NMR spectroscopy as an average of three independent experiments.

Pd loading	R	Time (h)	Conversion (%)	(SD)
1 mol%	Me	2	94	(± 1)
	Et		43	(± 1)
	Pr^i		52	(± 4)
	CH_2CF_3		93	(± 3)
2 mol%	Me	2	99	(± 1)
	EtOH		81	(± 3)
	Pr^i		75	(± 4)
	CH_2CF_3		99	(± 1)

Table S4-3. Transformation of benzo[*h*]quinoline to 10-alkoxybenzo[*h*]quinoline catalysed by **1** (1-3 mol%) in different solvents at 50 °C using 2 equivalents of $PhI(OAc)_2$. The rate of conversion to the desired product was determined by ^1H NMR spectroscopy as an average of three independent experiments.

Solvent	**Loading**	**t (h)**	**Conversion (%)**
MeOH	1 mol%	2	79 (±3)
MeOH	1 mol%	4	88 (±1)
MeOH	1 mol%	6	92 (±1)
MeOH	1 mol%	24	98 (±1)
MeOH	2 mol%	2	98 (±1)
MeOH	2 mol%	4	99 (±1)
MeOH	2 mol%	6	99 (±1)
MeOH	2 mol%	24	99 (±1)
MeOH	3 mol%	2	91 (±2)
MeOH	3 mol%	4	97 (±3)
MeOH	3 mol%	6	99 (±1)
MeOH	3 mol%	24	99 (±1)
EtOH	1 mol%	2	39 (±1)
EtOH	1 mol%	4	38 (±1)
EtOH	1 mol%	6	39 (±1)
EtOH	1 mol%	24	39 (±1)
EtOH	2 mol%	2	97 (±1)
EtOH	2 mol%	4	97(±1)
EtOH	2 mol%	6	97 (±2)
EtOH	2 mol%	24	99 (±1)
EtOH	3 mol%	2	95 (±2)
EtOH	3 mol%	4	97 (±2)
EtOH	3 mol%	6	98 (±1)
EtOH	3 mol%	24	99 (±1)
Pr^iOH / AcOH	1 mol%	2	33 (±1)
Pr^iOH / AcOH	1 mol%	4	38 (±2)
Pr^iOH / AcOH	1 mol%	6	40 (±1)
Pr^iOH / AcOH	1 mol%	24	47 (±2)
Pr^iOH / AcOH	2 mol%	2	68 (±1)
Pr^iOH / AcOH	2 mol%	4	73 (±2)
Pr^iOH / AcOH	2 mol%	6	77 (±1)
Pr^iOH / AcOH	2 mol%	24	82 (±4)
Pr^iOH / AcOH	3 mol%	2	88 (±2)
Pr^iOH / AcOH	3 mol%	4	92 (±3)
Pr^iOH / AcOH	3 mol%	6	96 (±1)
Pr^iOH / AcOH	3 mol%	24	99 (±1)
CF_3CH_2OH	1 mol%	2	64 (±1)
CF_3CH_2OH	1 mol%	4	71 (±1)
CF_3CH_2OH	1 mol%	6	76 (±1)
CF_3CH_2OH	1 mol%	24	90 (±1)
CF_3CH_2OH	2 mol%	2	95 (±2)
CF_3CH_2OH	2 mol%	4	98 (±1)
CF_3CH_2OH	2 mol%	6	99 (±1)
CF_3CH_2OH	2 mol%	24	99 (±1)
CF_3CH_2OH	3 mol%	2	99 (±1)
CF_3CH_2OH	3 mol%	4	99 (±1)
CF_3CH_2OH	3 mol%	6	99 (±1)
CF_3CH_2OH	3 mol%	24	99 (±1)

Table S4-4. Transformation of benzo[*h*]quinoline to 10-alkoxybenzo[*h*]quinoline catalysed by PdI_2(dppf) **2** (1 or 2 mol%) in different solvents at 50 or 75 °C using 2 equivalents of $PhI(OAc)_2$. The rate of conversion to the desired product was determined by ^1H NMR spectroscopy as an average of three independent experiments.

Solvent	t (h)	Conversion (%) 1 mol% [Pd] 50 °C	Conversion (%) 2 mol% [Pd] 50 °C	Conversion (%) 2 mol% [Pd] 75 °C
MeOH	2	98 ± 1	87 ± 2	-
	4	99 ± 1	99 ± 1	-
	6	99 ± 1	99 ± 1	-
	24	99 ± 1	99 ± 1	-
EtOH	2	21 ± 1	68 ± 1	81 ± 1
	4	24 ± 1	66 ± 1	81 ± 3
	6	28 ± 1	68 ± 1	-
	24	29 ± 2	67 ± 2	82 ± 1
CF_3CH_2OH	2	54 ± 1	80 ± 3	-
	4	76 ± 1	94 ± 3	-
	6	86 ± 1	99 ± 1	-
	24	99 ± 1	99 ± 1	-
iPrOH	2	33 ± 1	54 ± 4	-
	4	47 ± 1	71± 1	-
	6	54 ± 1	77 ± 1	-
	24	74 ± 1	95 ± 1	-

Table S4-5. Transformation of 8-methylquinoline to 8-(methoxymethyl)quinoline using **1** or **2** as catalysts (1 or 2 mol% [Pd]) in different solvents at 50 °C using 2 equivalents of $PhI(OAc)_2$. The rate of conversion to the desired product was determined by ^1H NMR spectroscopy as an average of three independent experiments.

Catalysts	Solvent	Loading	t (h)	Conversion (%)
$[N^nBu_4]_2[Pd_2I_6]$ (**1**)	MeOH	1 mol %	2	96 ± 1
			4	94 ± 2
			6	96 ± 1
			24	95 ± 1
		2 mol %	2	99 ± 1
			4	99 ± 1
			6	99 ± 1
			24	99 ± 1
PdI_2(dppf) (**2**)	MeOH	1 mol %	2	73 ± 2
			4	80 ± 2
			6	77 ± 3
			24	81 ± 1
		2 mol %	2	80 ± 1
			4	81 ± 3
			6	80 ± 1
			24	85 ± 2

S5 Data for amination reactions

Table S5-1. Reaction conditions for the amination of *p*-bromobiphenyl with *p*-toluidine in CPME in the presence of ^{t}BuOK at 100 °C used to generate data for DoE analysis.

Reaction	Time (min)	Pd loading (mol%)	dppf (mol%)	Conversion to product (%)	Ar-Br residual (%)	Mass balance
1	120	5	15	64.2	24.3	88.5
2	120	3	15	68.3	28.1	96.4
3	30	5	15	47.5	51.6	99.1
4	120	5	3	58.2	19.1	77.3
5	75	1	15	35.4	72.9	108.3
6	75	3	3	65.2	27.4	92.6
7	30	1	3	36.5	64.2	100.6
8	30	1	15	8.5	91.8	100.3
9	30	5	3	55.2	39.9	95.1
10	77.7	5	9.48	62.7	18.3	81.0
11	30	3	9	43.8	53.0	96.7
12	75	1	3	71.5	24.1	95.6
13	30	1	9	18.4	80.3	98.6
14	120	1	15	53.4	43.3	96.7
15	30	5	3	54.3	36.4	90.7
16	120	5	3	61.9	22.8	84.7
17	30	5	15	52.9	41.9	94.8
18	120	1	9	58.9	40.5	99.5
19	120	3	3	70.5	18.3	88.8
20	120	1	3	79.1	16.3	95.5

Table S5-2. Reaction profile for the amination of *p*-bromobiphenyl with *p*-toluidine against time. The rate of conversion to the desired product was determined by ^{1}H NMR spectroscopy.

Time (min)	Conversion (%)
0	0
2	21
5	36
10	56
20	69
30	77
60	84
120	85
180	90