Australian Government
Department of Agriculture
ABARES

# Climate adjusted total factor productivity for Australian broad-acre farms: 1989 to 2018

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**Australian Bureau of Agricultural and Resource Economics and Sciences**

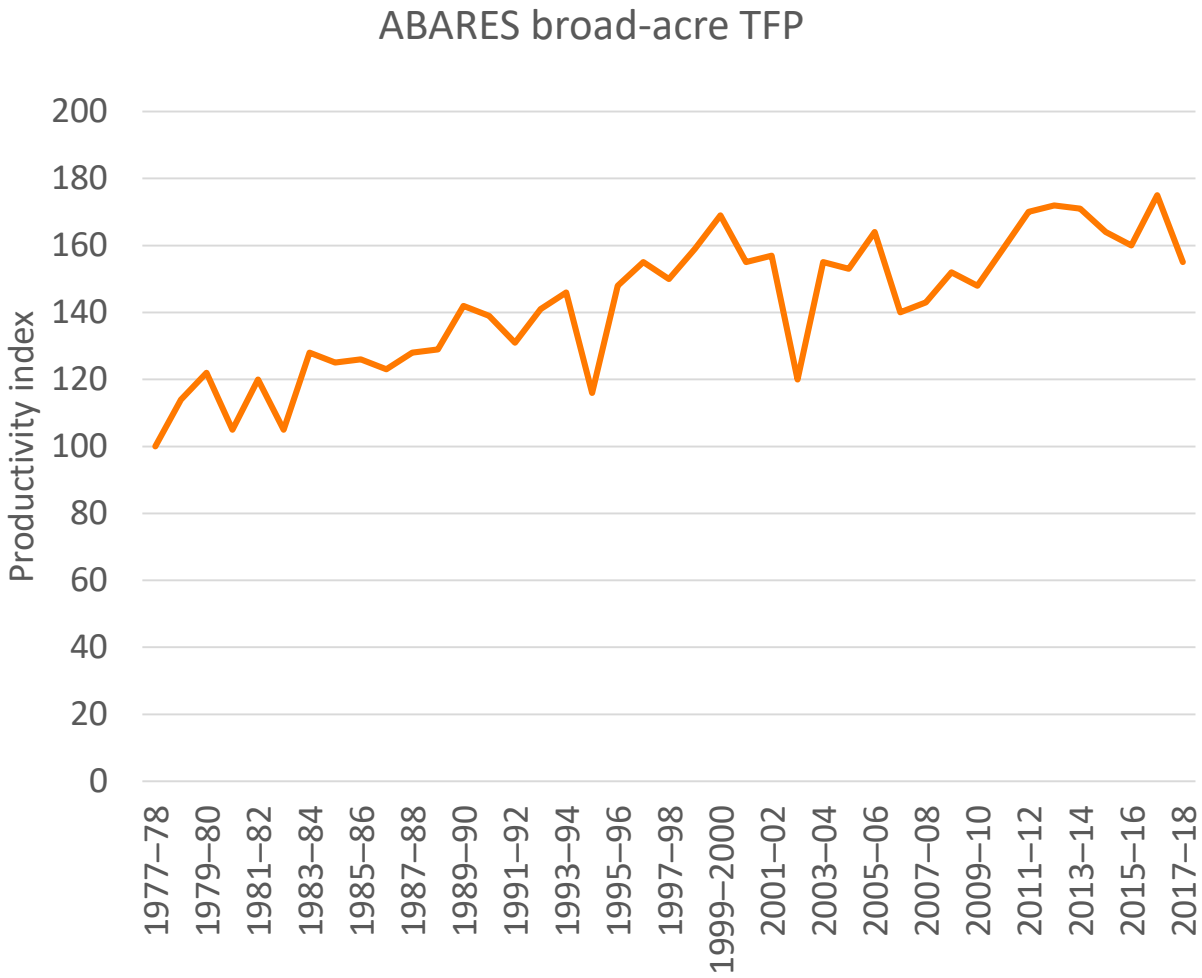
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Research by the
Australian Bureau of Agricultural and Resource Economics and Sciences

# Some background

- Why adjust for climate?
  - Actual productivity improvement obscured by seasonal volatility
  - Implications for policy makers and statistical users.
  - Climate change

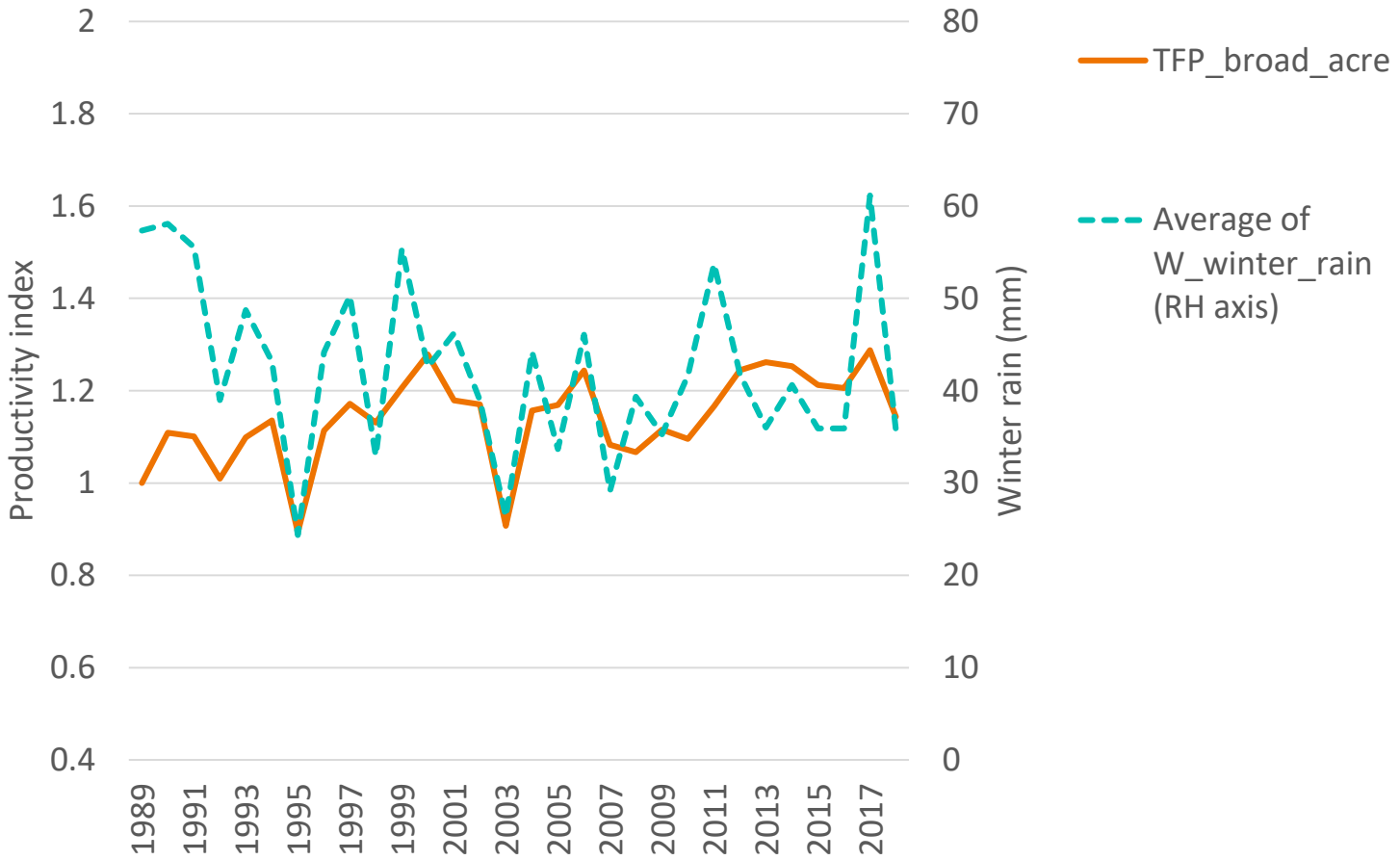



*Source: ABARES*

# The relationship between TFP and climate

- TFP is exposed to seasonal variability
  - Cropping is highly sensitive to winter rainfall
  - Livestock affected by temperature

**Broad-acre TFP (UNADJUSTED) and average winter rainfall, 1989 to 2018**

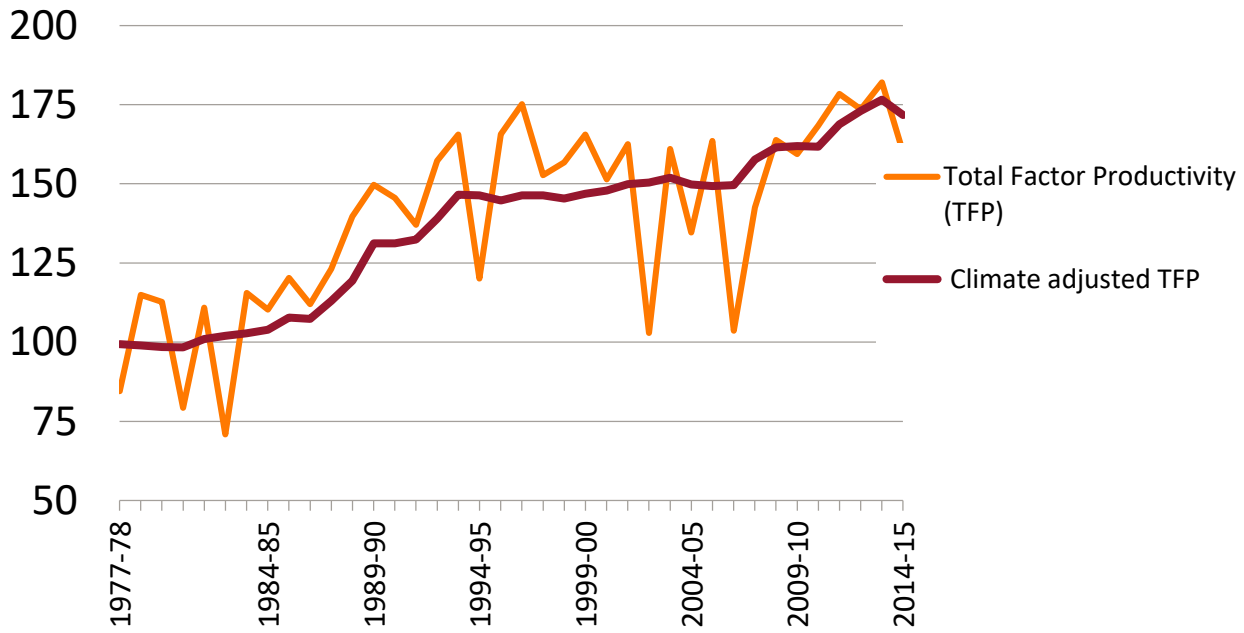



*Source: Authors estimates and Hughes et al. 2019 (farmPredict)*

# Previous work – climate adjusted cropping TFP

- Climate adjusted cropping TFP (Hughes et al. 2017)
  - Short term volatility largely explained by seasonal variation
  - Climate conditions for cropping deteriorating
  - Crop farmers adapting

**Climate adjusted TFP for the Australian broad-acre cropping industry, 1977-78 to 2014-15**




Hughes, N, Lawson, K & Valle, H 2017, *Farm performance and climate: Climate-adjusted productivity for broadacre cropping farms*, Canberra, April.
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# Climate adjusted TFP approach

## Previous approach

$TFP_{it} = f(W_{it}, t)$ Fit regression model of farm-level TFP against climate and other controls

$TFPCA_{it} = \frac{1}{s}\sum_s f\ (W_{is}, t)$ Simulate TFP for range of climate years *s* and take average

## New approach

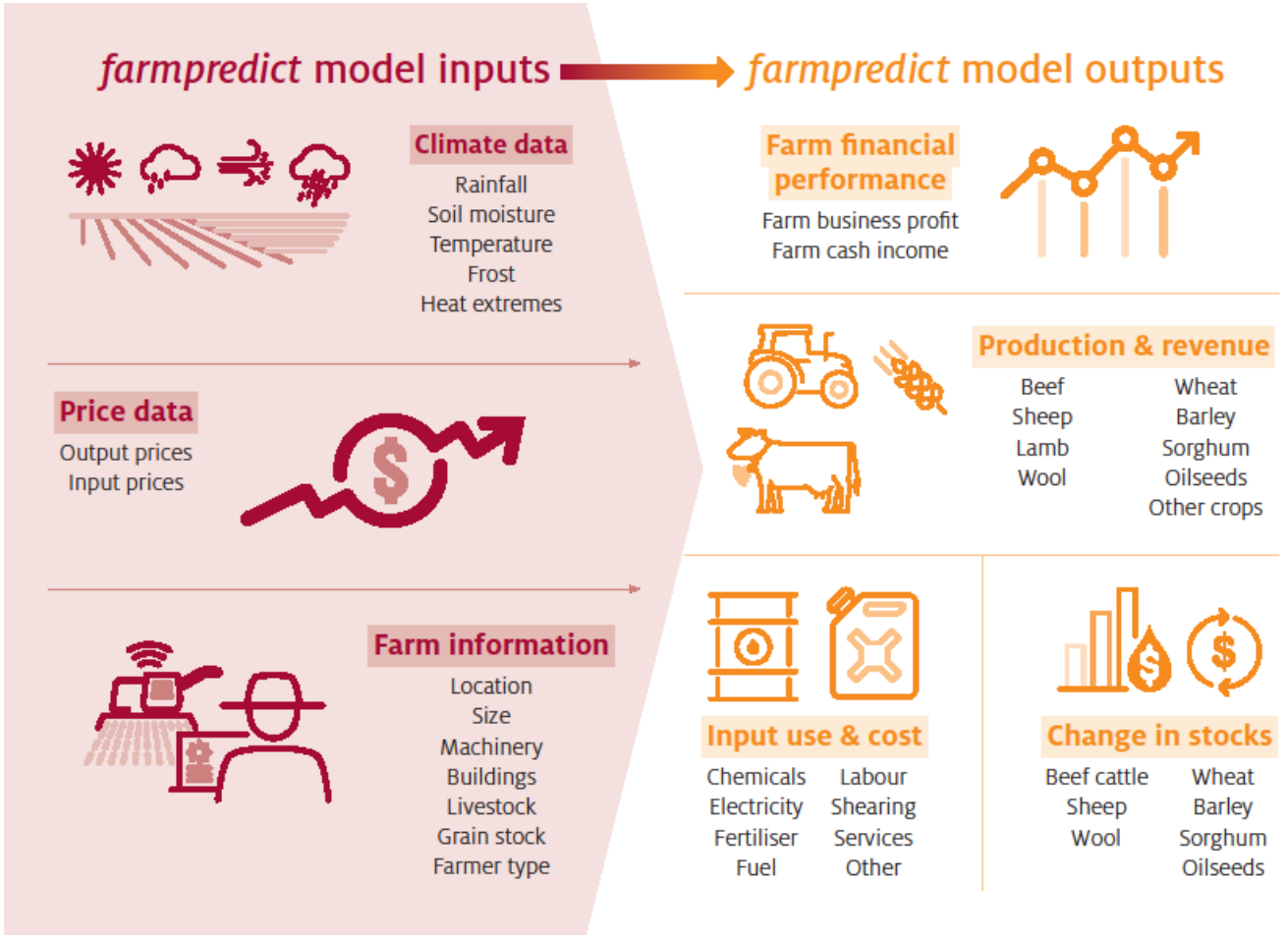
$\boldsymbol{Q}_{it,}\boldsymbol{V}_{it} = \boldsymbol{f}(W_{it}, K_{it}, t)$ *farmpredict* (outputs and variable inputs as a function of climate, fixed inputs and other controls)

$\boldsymbol{Q}_{its,}\boldsymbol{V}_{its} = \boldsymbol{f}(W_{is}, K_{it}, t)$ Simulate outputs and inputs under a range of climate years *s*

$TFPCA_{it} = \frac{1}{s}\sum_s g\ (\boldsymbol{Q}_{its}, \boldsymbol{V}_{its})$ Compute TFP using index formula *g* for every climate year *s* and take average

# *farmpredict*

- **Data driven**
  - Farm production / financial data
  - Site specific climate data
- **Micro-simulation statistical model**
  - Series of input demand and output supply functions
  - Similar to 'dual' (reduced form) production models
- **Machine learning estimation**
  - Gradient boosted regression tree
  - Multi-target stacking
  - Cross validation
- **Farm level simulation**
  - Climate, price, technology, scale




Hughes, N. Soh, W. Y., Boult, C., Lawson, K., Donoghoe, M., Valle, H. and Chancellor, W., 2019, ***farmpredict:* A micro simulation model of Australian farms**, ABARES working paper, Canberra

# Data and variables

- TFP input and output
  - Follows ABARES TFP index structure
- Unbalanced panel
  - 1989-2018
  - 54 analysis variables for TFP

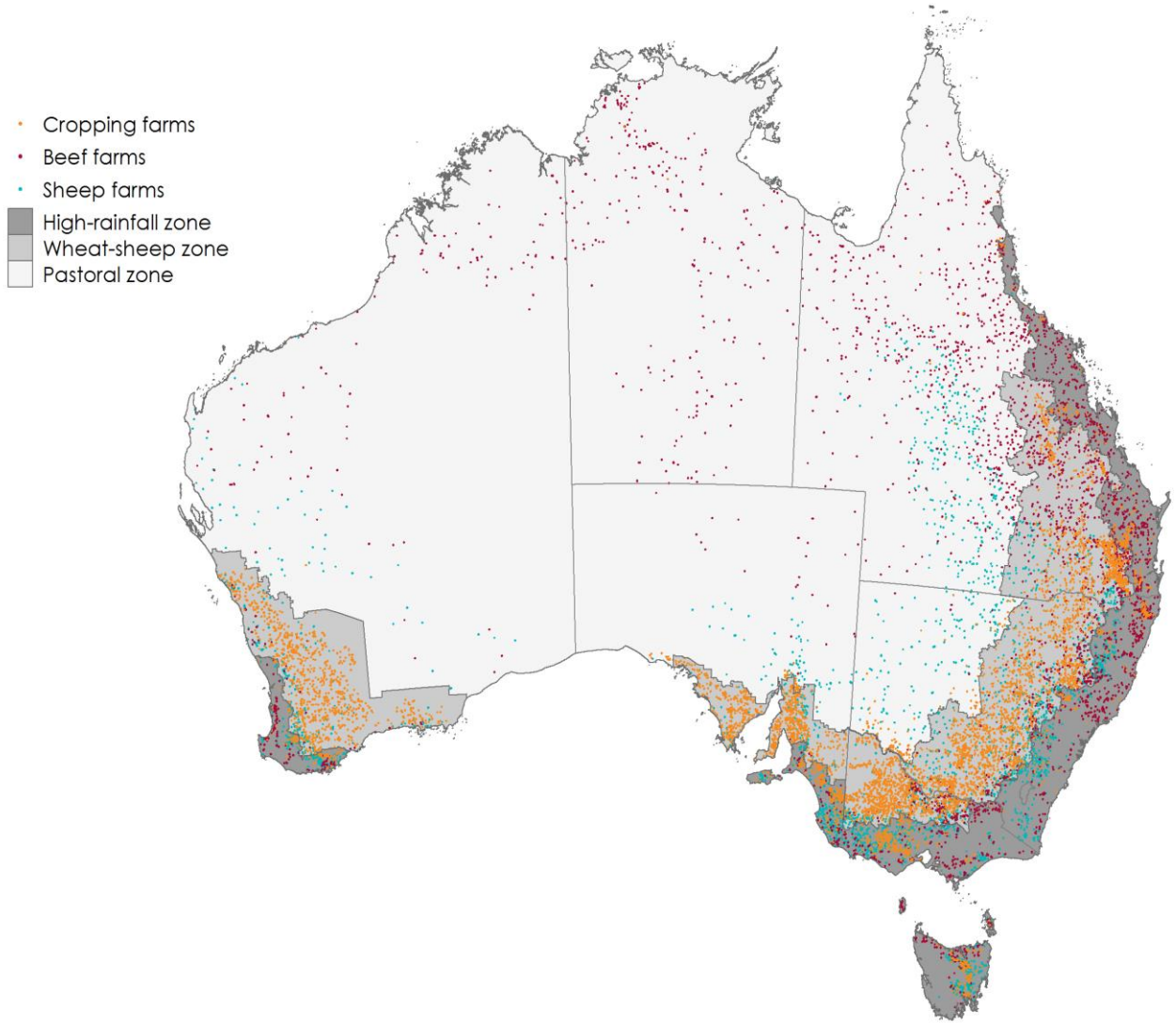
**Total factor productivity variables**

| | Output quantity | Output price | Source |
|---|---|---|---|
| 1 | Beef cattle output | Beef farm price (index) | farmpredict |
| 2 | Sheep output | Sheep farm price (index) | farmpredict |
| 3 | Wool produced (Kg.) | Wool price (index) | farmpredict |
| 4 | Prime lamb sold (no.) | Lamb price | farmpredict |
| 5 | Wheat harvested (t) | Wheat farm price (index) | farmpredict |
| 6 | Barley harvested (t) | Barley farm price (index) | farmpredict |
| 7 | Sorghum harvested (t) | Sorghum farm price (index) | farmpredict |
| 8 | Oilseeds harvested (t) | Oilseeds farm price (index) | farmpredict |
| 9 | Other crops sold (index) | Other crop price (index) | farmpredict |
| 10 | Other revenue ($) | Other revenue price (index) | farmpredict |
| | | | |
| | **Input quantity** | **Input price** | **Source** |
| 1 | Fertiliser (index) | Fertiliser price (index) | farmpredict |
| 2 | Fuel, oil and grease (index) | Fuel, oil and grease price (index) | farmpredict |
| 3 | Crop and pasture chemicals (index) | Crop and pasture chemicals (index) | farmpredict |
| 4 | Other materials (index) | Other materials (index) | farmpredict |
| 5 | Services (index) | Other services (index) | farmpredict |
| 7 | Family labour (index) | Constant (index) | farmpredict |
| 8 | Hired labour shearing (index) | Hired labour shearing (index) | farmpredict |
| 9 | Other costs (index) | Other costs (index) | farmpredict |
| 10 | Beef input | Beef farm price (index) | farmpredict |
| 11 | Sheep input | Sheep farm price (index) | farmpredict |
| 12 | Beef capital | Beef cattle value in herd (real) ($) | AAGIS |
| 13 | Sheep capital | Sheep value in herd (real) ($) | AAGIS |
| 14 | Other livestock capital | Other livestock slaughter price (index) | AAGIS |
| 15 | Land area (ha.) | Land value (real) ($) | AAGIS |
| 16 | Buildings and improvements | Fixed improvements (real) ($) | AAGIS |
| 17 | Equipment and machines | Plant and equipment (real) ($) | AAGIS |
| | | | |
| | **Classification variables** | | |
| 1 | Farm number (unit identifier) | | farmpredict |
| 2 | Year (YYYY) | | farmpredict |
| 3 | Weight | | farmpredict |
| 4 | State (1=NSW, 2=VIC, 3=QLD, 4=SA, 5=WA, 6=TAS) | | farmpredict |
| 5 | Industry (1=Cropping, 2=Mixed crop-livestock, 3=Sheep, 4=Beef, 5=Sheep-beef) | | farmpredict |

[1] *Beef cattle output=beef cattle receipts+increase in herd size*
[2] *sheep output=sheep receipts+increase in flock size*
[3] *Beef input=expenditure on beef cattle+decrease in herd size*
[4] *Sheep input=expenditure on sheep+decrease in flock size*
[5] *Land value=total average capital-(average livestock capital value+average value of crops and wool on hand+average leased plant and equipment capital value+average non leased plant and equipment capital value+operators house value+farm fixed improvements value)*

# Data and variables

- Wheat sheep zone
  - Mostly large scale cropping
- High rainfall zone
  - Mostly small scale livestock (where rainfall is too high for cropping and land is too expensive)
- Pastoral zone
  - Mostly large scale livestock (where rainfall is too low for cropping)



# Data and variables

- Site specific climate data
  - AWAP and AWRA-L (5km grid)
  - SILO and BoM based on nearest weather station

**Climate variables used in *farmpredict***

| | Climate variables | Unit | Source |
|---|---|---|---|
| **1** | Rainfall volume | Mm | AWAP |
| **2** | Average maximum temperature | Degrees C | AWAP |
| **3** | Average minimum temperature | Degrees C | AWAP |
| **4** | Root zone soil moisture | Index (0-1) | AWRAL |
| **5** | Exposure to frost (days below 2C) | Days | SILO |
| **6** | Heat accumulation (growing degree days) | Degrees C | SILO |
| **7** | Exposure to high temperatures | Degrees C | SILO |
| **8** | Rainfall volatility (Gini coefficient) | Index | SILO |
| **9** | Rainfall volatility | Index | SILO |
| **10** | Exposure to hail storms | Index (0-1) | BoM |

[1] Australian Water Availability Project
[2] Australian Water Resources Assessment Landscape
[3] Scientific Information for Land Owners
[4] Bureau of Meteorology

# Method for climate scenario simulation

- Method outlined in Hughes et al. 2019 '*farmpredict*'
- *Non-parametric machine learning with gradient boosted regression tree algorithm (xgboost) and multi-target stacking (two stage regression)*

Generates farm level predictions for multiple dependent variables $Y_{it}$ as a function of a large number of explanatory variables:

$$X_{it} = \{P_t, K_{it}, S_{it}^{op}, W_{it}, Z_{it}\}$$

Where $P_t$ are price indexes for each output and input,
$K_{it}$ are the quantity of capital input,
$S_{it}^{op}$ are the opening quantities of stock $s$,
$W_{it}$ are weather indicators, and
$Z_{it}$ are a collection of control variables (Hughes et al. 2019).

# Method for climate scenario simulation

- Target variables (outputs $Q$, revenue $R$, variable inputs $V$, costs $C$ and closing stocks $S^{cl}$) can then be predicted by using explanatory variables (Fixed inputs $K$, opening stocks $S^{op}$, prices $P$, climate $W$, and controls $Z$).

- Therefore, for farm $i$ in period $t$, prediction of target variables:

$$\hat{Y}_{it} = \{Q_{it}, R_{it}, V_{it}, C_{it}, S_{it}^{cl}\}$$

*Are a function of explanatory variables:*

$$X_{it} = \{P_t, K_{it}, S_{it}^{op}, W_{it}, Z_{it}\}$$

# Practical climate adjustment

- Run climate scenarios on farm level data
  - farmpredict used to run simulated climate scenarios (1989, 1990…2018) to farm level panel data (30 panels)
- Run TFP model using each panel
  - TFP estimated 30 times (to produce TFP under climate scenario 1989 to 2018)
- Calculate average TFP index
  - An average of these 30 indexes is taken to derive TFP under average climate.

# ABARES TFP indexes

- Fisher index
  - Geometric mean of Laspeyres and Paasche
- EKS (transitivity)
  - Desirable index number properties for transitivity and circularity
  - More information on ABARES TFP method [EKS Fisher index]from Zhao et al. (2012)

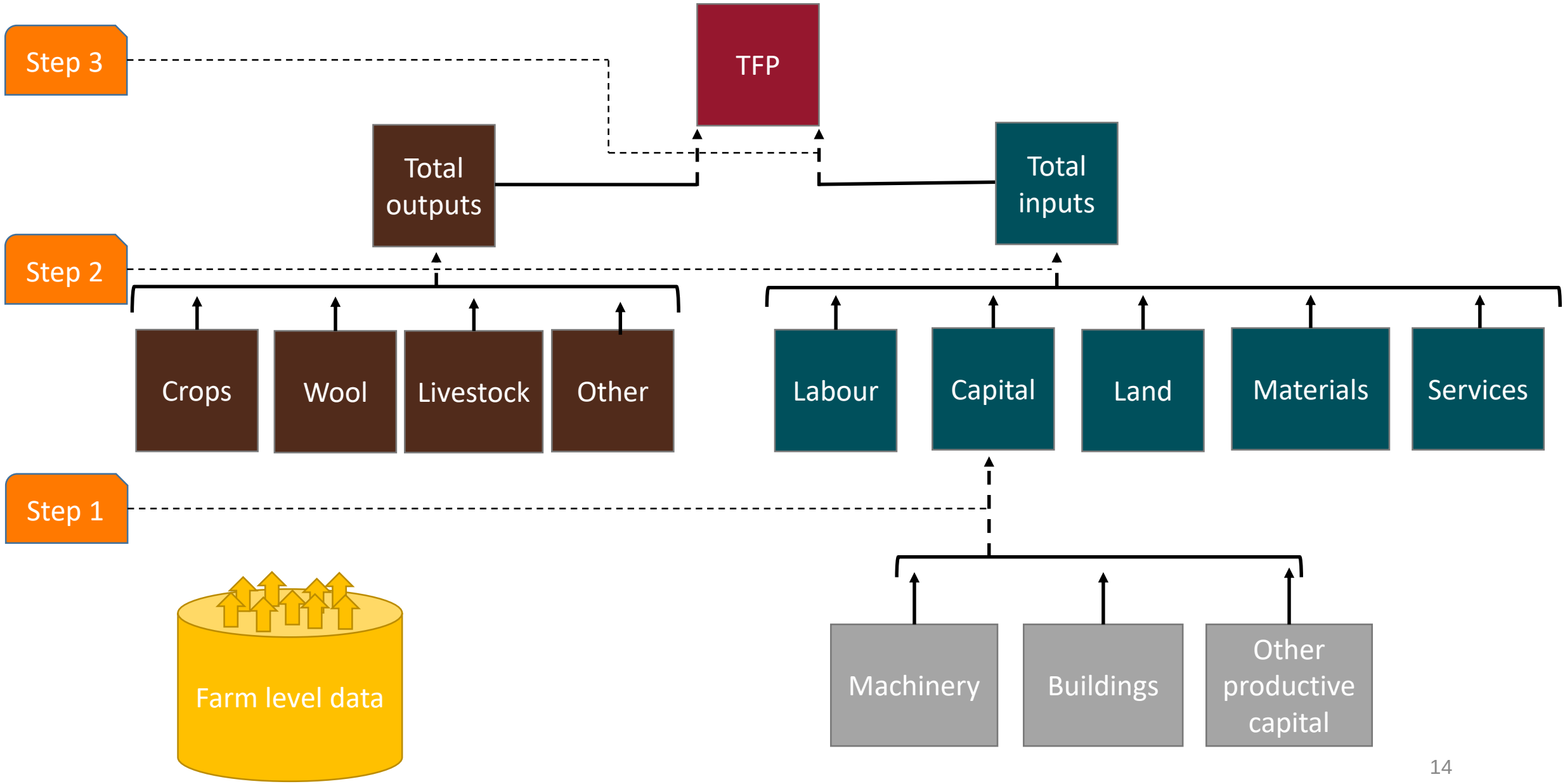
$$Q_{0t}^{F} = \sqrt{Q_{0t}^{L} Q_{0t}^{P}}$$

$$Q_{0t}^{L} = \frac{\sum_{i=1}^{N} p_{i0}\, q_{it}}{\sum_{i=1}^{N} p_{i0}\, q_{i0}} = \sum_{i=1}^{N} W_{i0} \frac{q_{it}}{q_{i0}}$$

$$Q_{0t}^{P} = \frac{\sum_{i=1}^{N} p_{it}\, q_{it}}{\sum_{i=1}^{N} p_{it}\, q_{is}} = \left\{ \sum_{i=1}^{N} W_{it} \left( \frac{q_{i0}}{q_{it}} \right) \right\}^{-1}$$

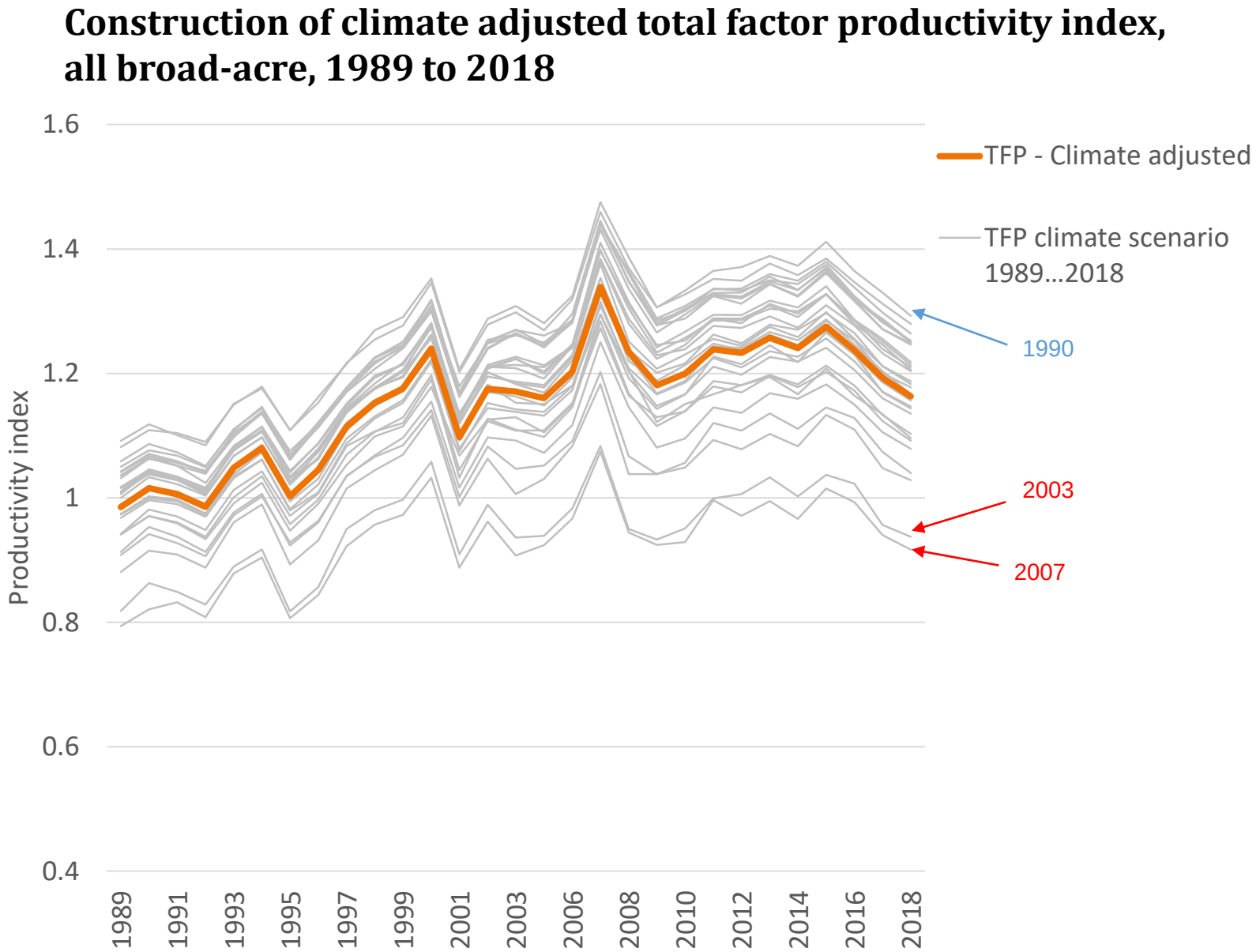
$$Q_{AB}^{EKS} = \left( \prod_{r=1}^{N} Q_{AC}^{F}\, Q_{CB}^{F} \right)^{1/N}$$

# ABARES TFP measurement



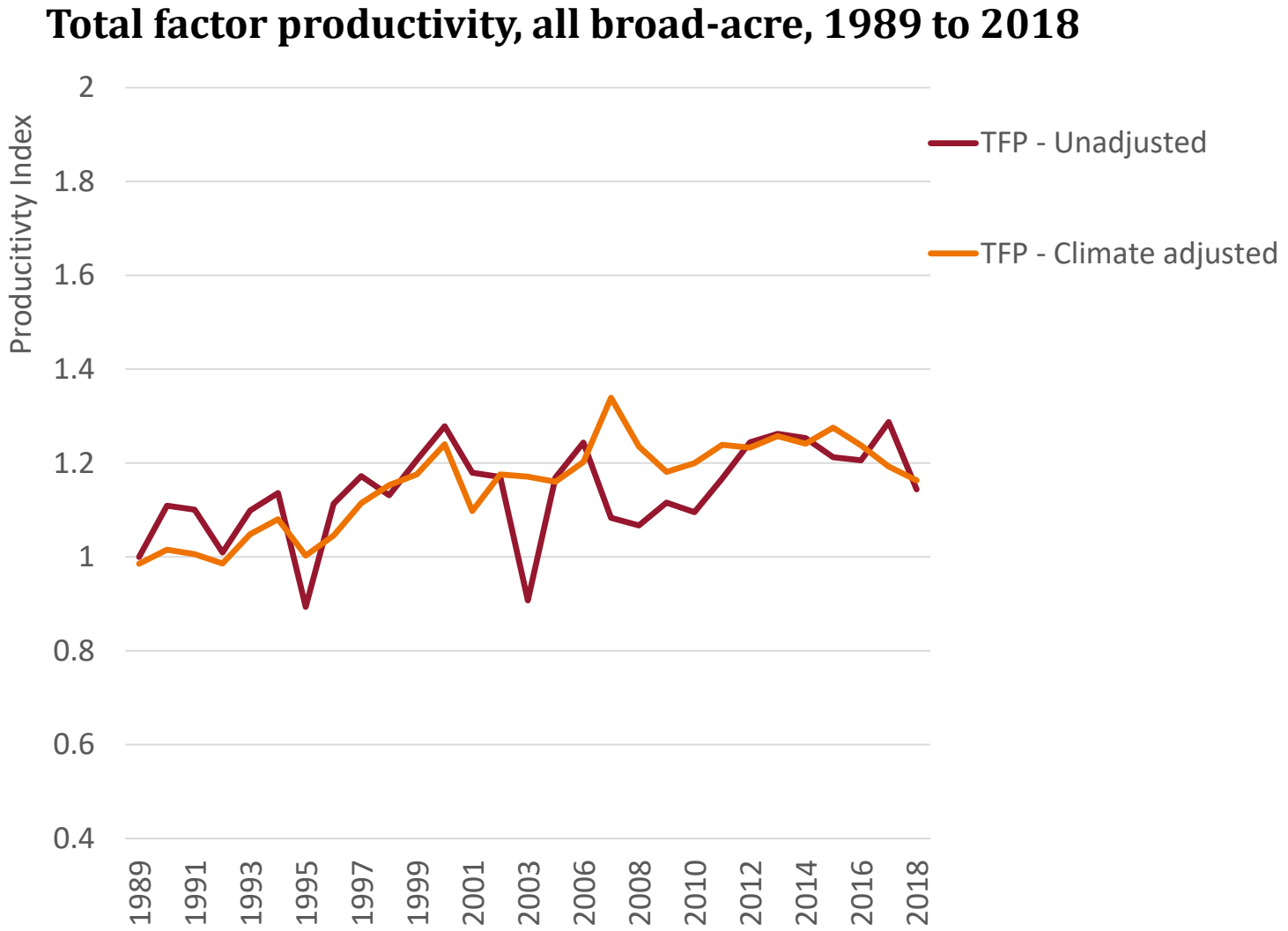
# Average climate scenario

- Multiple climate scenarios
  - 1989…2018
- TFP under ‘average climate’
- Process repeated for all broad-acre industries



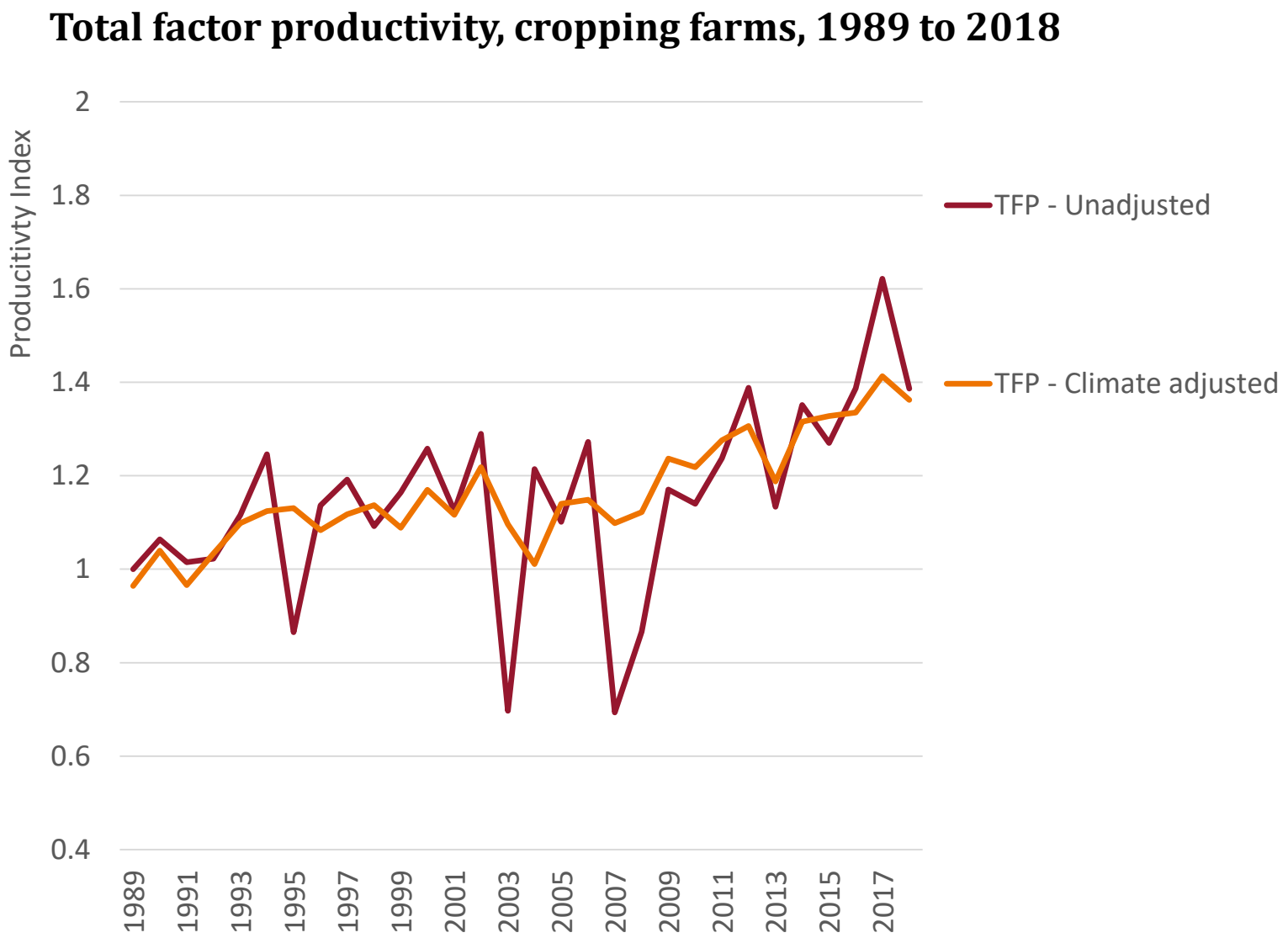
# Results – all broad-acre

- Short term seasonal volatility largely smoothed
- Post-drought improvements in TFP



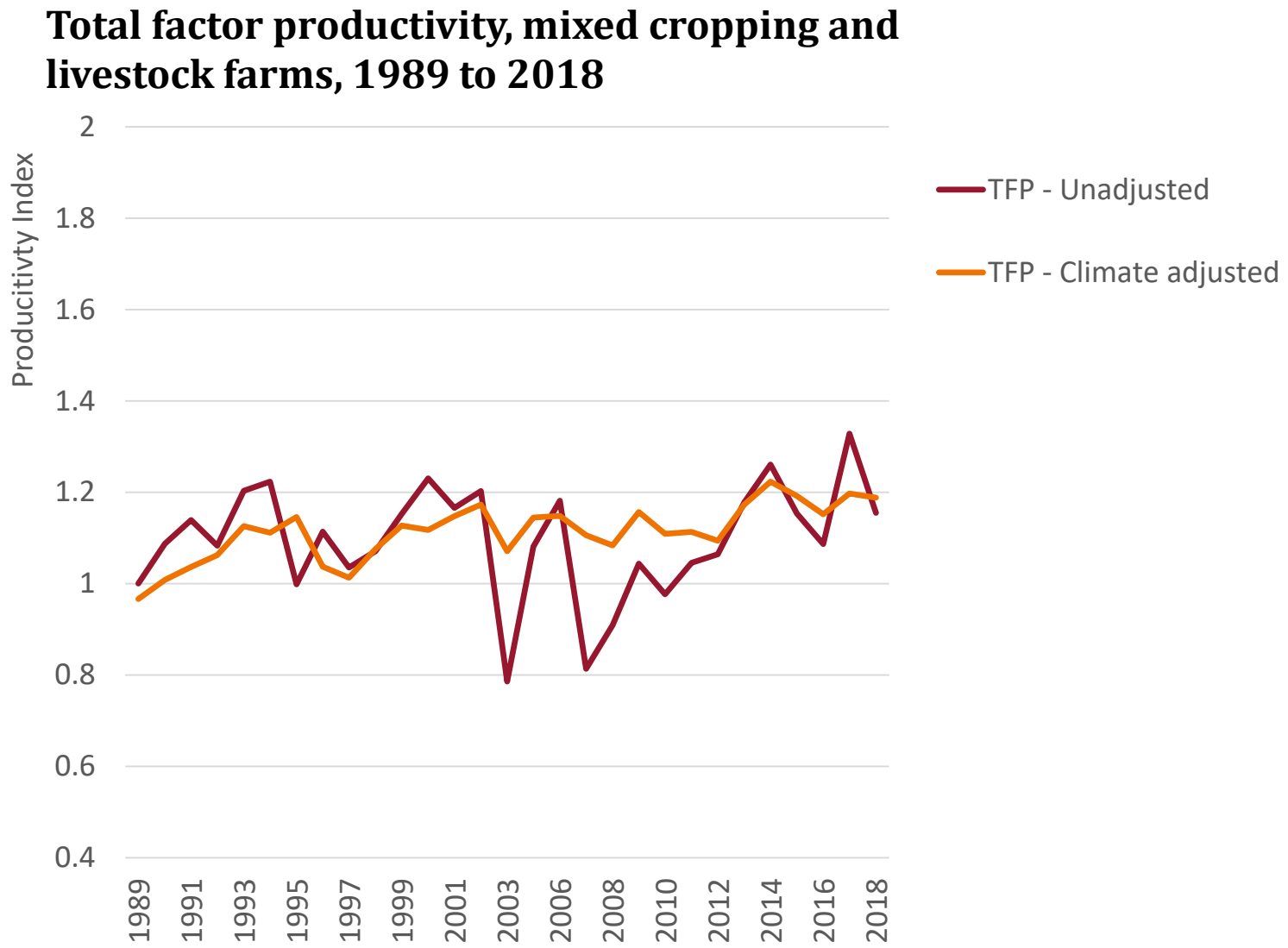
# Results – Cropping

- Cropping sensitive to rainfall
  - Drought years smoothed (e.g. 2003, 2007)
  - High rainfall years smoothed (e.g. 2017)
- Climate adjusted TFP trend suggests adaptation



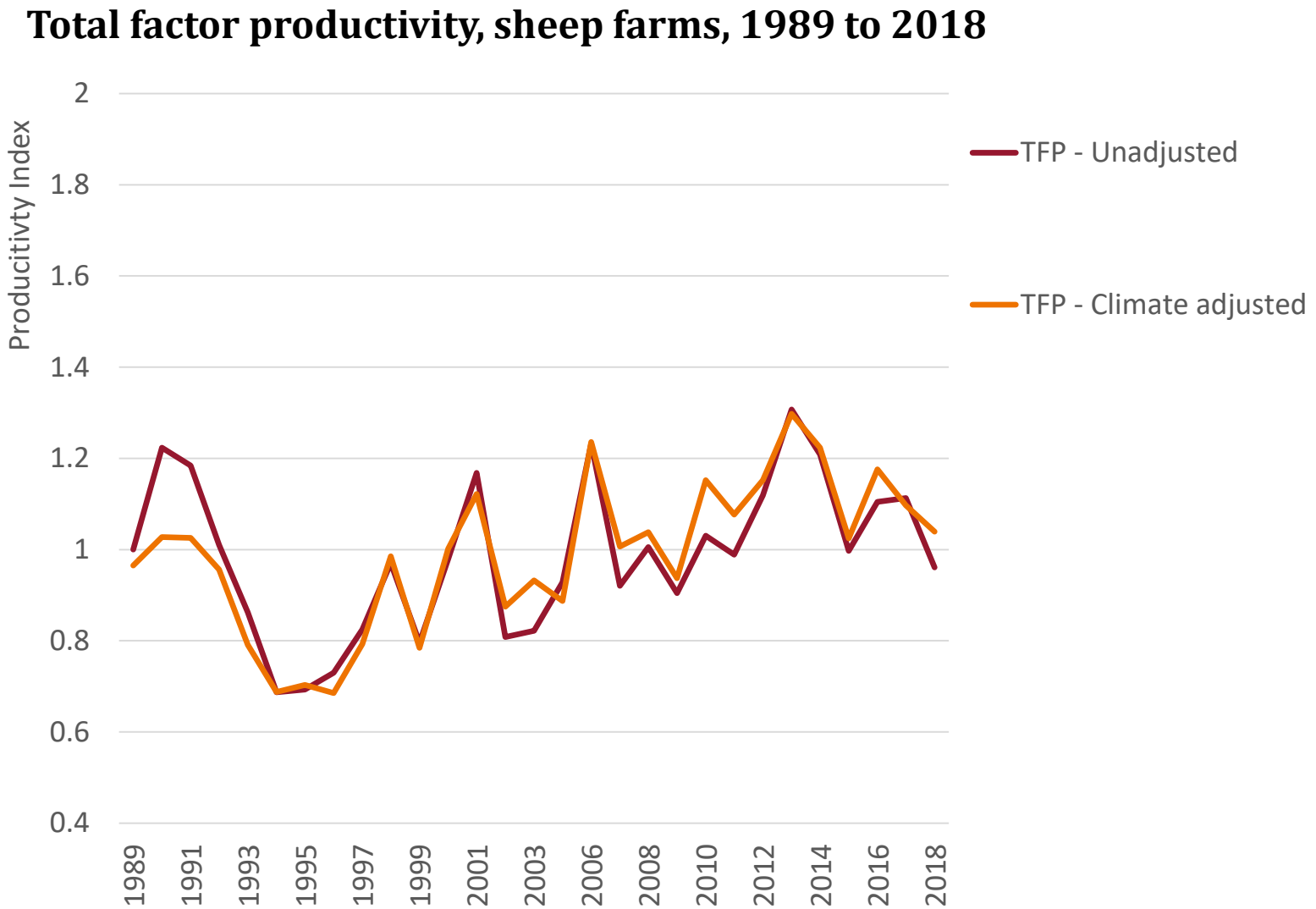
# Results – Mixed (crop / livestock)

- Mixed farms less exposed to climate variation
  - Diversification



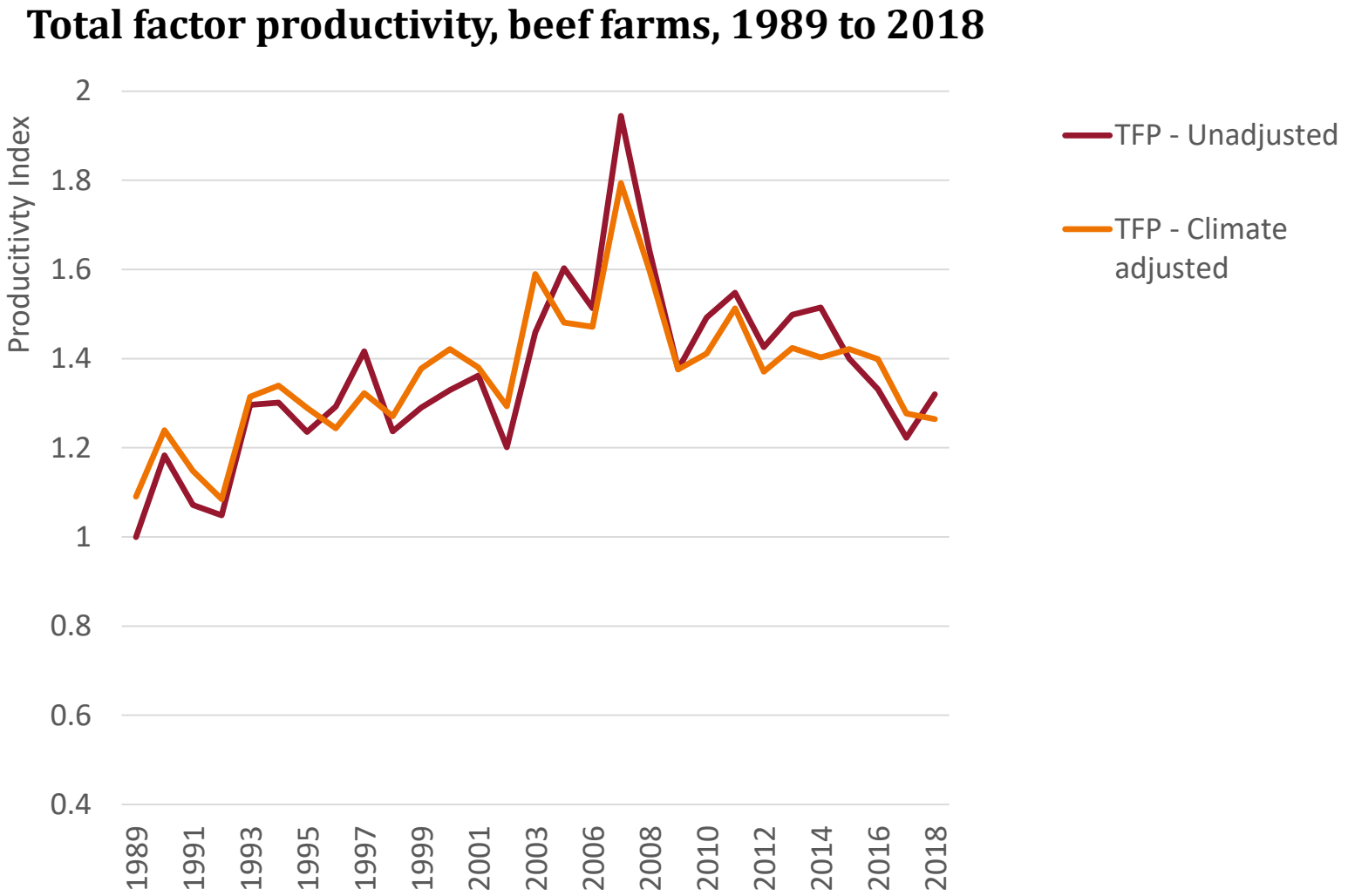
# Results – Sheep

- Sheep farms appear less sensitive to climate
- Further investigation
  - Structural break
  - Industry transformation



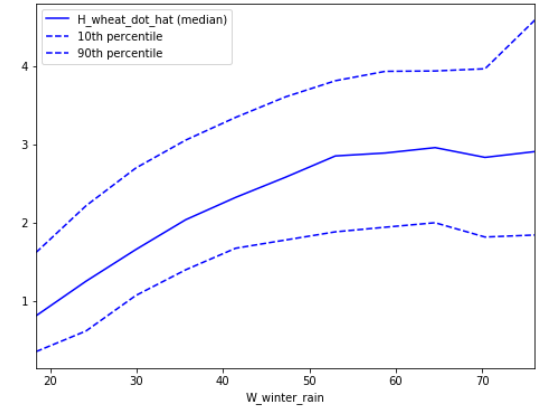
# Results – Beef

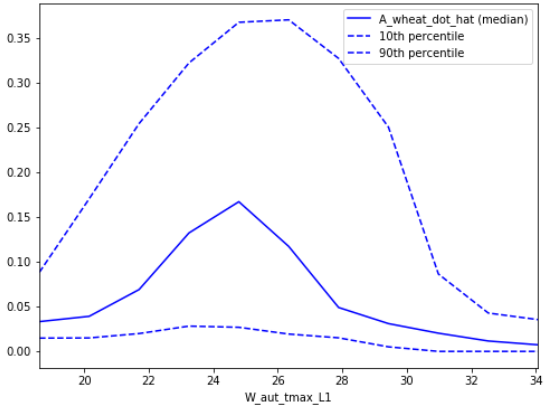
- Beef farms also appear less sensitive to climate
  - Relationship between temperature and stocking rate identified
- Further investigation
  - Land input factor share

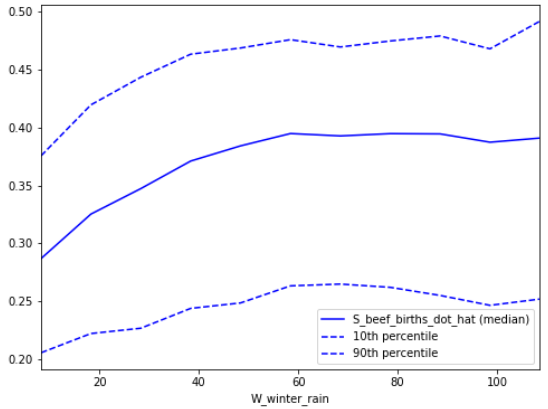


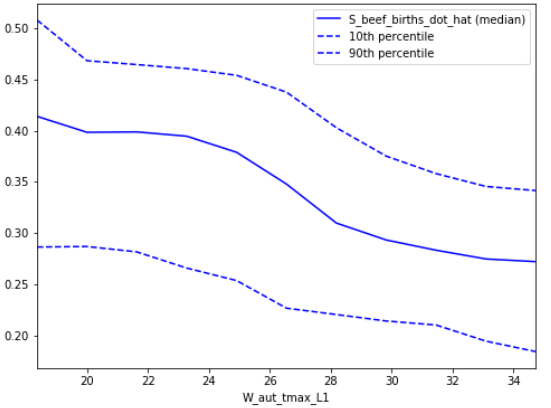
# Beef climate effect

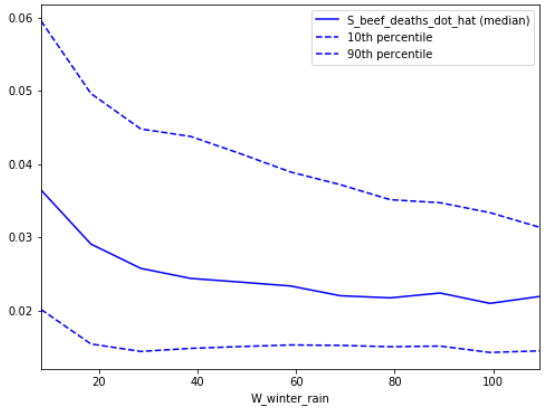
- Model response to growing season rainfall and Autumn avg. max. temp.
- Demonstrates there is some climate effect on beef

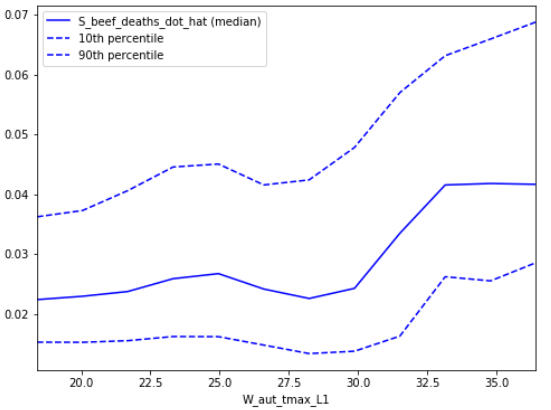


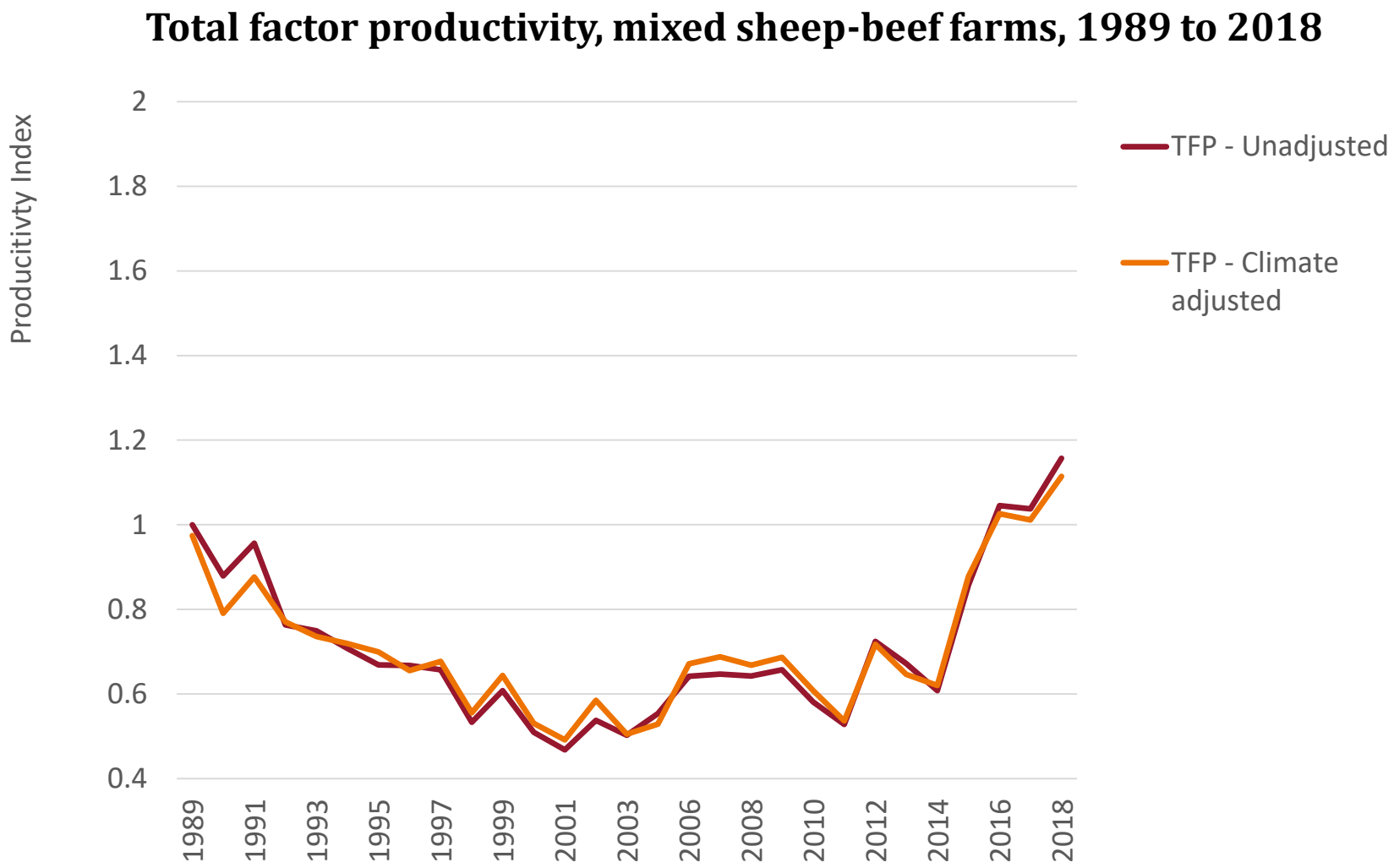



# Results – Mixed (sheep/beef)

- Beef-sheep
  - Little climate effect
- Further investigation
  - Volatile group, farms switching in and out.



# Future work

- Review of beef TFP (climate effect in stocking rates may be concealed by dominance of land input)
- Estimate climate adjusted TFP for dairy (different inputs and outputs compared to broad-acre).
- Look to publish climate adjusted TFP on annual basis.

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