Weather Shocks

Ewen Gallic[1,2] **and Gauthier Vermandel**[3,4]

[1]Aix Marseille Univ, AMSE, CNRS, Marseille, France
[2]CNRS – Université de Montréal CRM - CNRS
[3]PSL Research – Paris Dauphine University
[4]Ecole Polytechnique – Institut Polytechnique de Paris

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Ewen GALLIC

Environmental economics, data science, machine learning, algorithmic fairness

https://egallic.fr/

Gauthier VERMANDEL

Quantitative macroeconomics, climate change, inference of nonlinear structural models, and business cycle theory

https://vermandel.fr/

Aims of the paper

Some macro questions at hand:

- What are the **transmission mechanisms** of a **weather shock** both at sectoral and international levels?
- What are the **short run** and **long run** implications of **weather shocks**?
- How costly are weather fluctuations for households in terms of **welfare**?

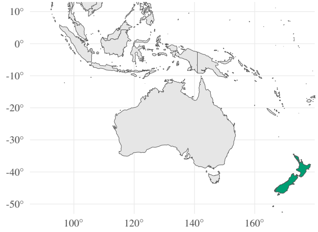
Methodology: 4 Steps

1. **Data pre-processing**
   - from daily weather **data** (grid/stations) to quarterly national values
   - **drought index** → narrow view of the weather (droughts and heat waves).
2. **Empirical Facts**
   - characterization a weather shock through the lens of a **VAR model**.
3. **Theoretical Model**
   - design and estimation of a **DSGE model** for a small open-economy
   - analysis of the **propagation** of a weather shock and its implications in terms of **business cycle statistics**.
4. **Scenarios**
   - we measure the implications of **climate change** on **aggregate fluctuations** by **increasing the variance of weather shocks**.

A Model for a Small Open Economy

In the paper, we focus on **New-Zealand**:

- New-Zealand has experienced **weather-driven recessions**:
  - 2013 – North Island + West of the South Island drought (cost: $1.3 billion / 0.5% of GDP)
  - 2008 – national drought (cost: $2.8 billion / 1.5% of GDP)
  - 2004 – lower North Island floods (cost: $185–$219 millions).
- New Zealand provides **very good quality data** (both for **weather** and **agriculture**).
- New Zealand is small enough to be subject to fairly homogeneous weather.



Our main results

1. Our model suggests that weather shocks play an important role in explaining macroeconomic fluctuations.
2. **Propagation of a weather shock**:
   - A **weather shock (drought event)** acts as a **standard negative supply shock** that hits the agricultural sector and spreads to the entire economy.
3. **Welfare costs**:
   - **Today**: welfare cost of weather shocks represents 0.40% **of households consumption**.
   - **Tomorrow**: this cost would reach up 0.59% **of household consumption because of climate change**.

Outline

1 Introduction

2 Building a Weather Index

3 Empirical Evidence with a VAR

4 An Estimated DSGE Model
- Estimation
- Business Cycle Analysis
- Climate Change

5 Opening remarks

2. Building a Weather Index

Measuring the Weather

- **Challenge**: computing at a macro level a weather index strongly correlated with real agricultural production.
- **Solution**: create **soil moisture deficit index**:
  1. Collect **soil water deficit** data from weather stations (on a monthly basis).
  2. Compute **percentage deviation from monthly median** as in Narasimhan and Srinivasan (2005): $D_{t,m} = \frac{SWD_{t,m} - Med(SWD_m)}{Med(SWD_m)}$ and include persistence of deficits, $SMDI_{t,m} = 0.5 \times SMDI_{t,m-1} + \frac{D_{t,m}}{50}$ that captures the evatransporation.
  3. Aggregation: compute an average per region, get national index by a weighting each region by its relative size in national agricultural production.
- In Crofils et al. (2025), we provide R codes to handle daily gridded weather data

Fig a: Weather stations in New Zealand

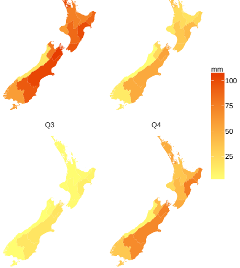


Fig b: Seasonality of Weather

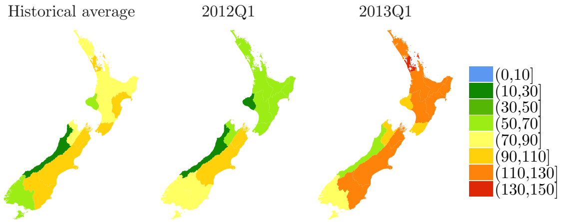


Fig c: Historical vs Normal times (2012:1) vs Drought (2013:1)

3. Empirical Evidence with a VAR

Gathering Empirical Evidence from a VAR

- **How does the weather affect the economy?**
- Some **empirical facts** collected from a VAR
- Some (fair) **assumptions** :
  - Small open economy: domestic variables $\nrightarrow$ foreign variables,
  - Weather is exogenous.
- **Data**: New Zealand 1994Q2 to 2016Q4 detrended using the HP filter with 7 variables.

Restricted VAR

The VAR reads as:

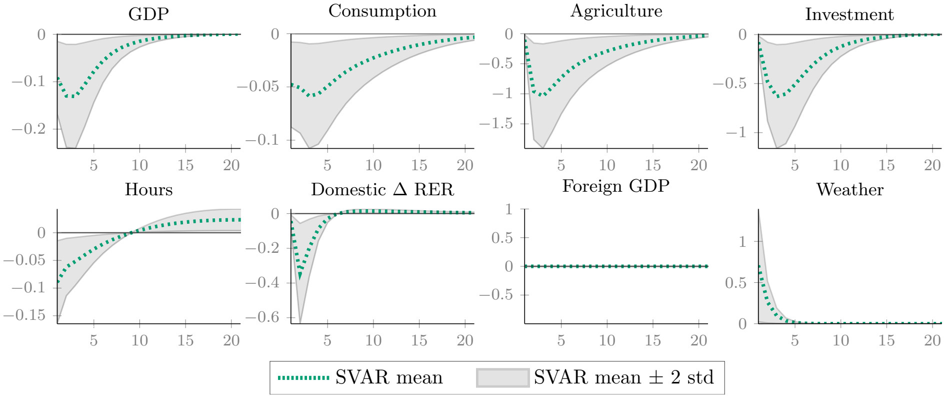
$$\begin{bmatrix} X_t^W \\ X_t^\star \\ X_t^D \end{bmatrix} = C + \sum_{l=1}^{p} \begin{bmatrix} A_l^{11} & 0 & 0 \\ 0 & A_l^{22} & 0 \\ A_l^{31} & A_l^{32} & A_l^{33} \end{bmatrix} \begin{bmatrix} X_{t-l}^W \\ X_{t-l}^\star \\ X_{t-l}^D \end{bmatrix} + \begin{bmatrix} \eta_t^W \\ \eta_t^\star \\ \eta_t^D \end{bmatrix}, \quad (1)$$

weather: $X_t^W = \hat{\omega}_t$; **foreign variable:** $X_t^\star = \hat{y}_t^\star$; **domestic block** :

$$X_t^D = \begin{bmatrix} \hat{y}_t & \hat{y}_t^A & \hat{\imath}_t & \hat{h}_t & \hat{q}_t & \widehat{rer}_t \end{bmatrix} \quad (2)$$

The **restrictions** reflect the assumptions (small open economy, exogeneity of weather).

Propagation of a Weather Shock (1/2)



Notes: Green line: **IRF**. Gray band: **95% error band** obtained from 10,000 Monte-Carlo simulations. Response horizon in quarters. Y-axis: percent deviation from the steady state.

Figure 1: SVAR impulse response to a 1% weather shock (drought) in New Zealand.

Propagation of a Weather Shock (2/2)

Business cycles facts :

1. A **weather shock (a drought)** generates a recession...
2. But hours worked remains acyclical ($\neq$a sectoral TFP shock).
3. Internationally, **weather** depresses the domestic real exchange rate (NZ\$ $\searrow$).

Next step : build a macro-model which features these business cycle facts.

4. An Estimated DSGE Model

A Sketch of the Model (1/3)

- **DSGE model** in an RBC framework (no nominal effects+rational expectations)
- Small open economy (home vs world)
- **Two sectors**:
  - weather-dependent agricultural sector (**original feature**)
  - standard non-agricultural sector
- **Weather shocks** affect the agricultural sector (**original feature**)

A Sketch of the Model (2/3)

1. Farmers face **exogenous weather**.

2. They can **offset** bad weather conditions by purchasing goods in the non-agricultural sector.

3. This leads to **spillover effects** between the two sectors.

A Sketch of the Model (3/3)

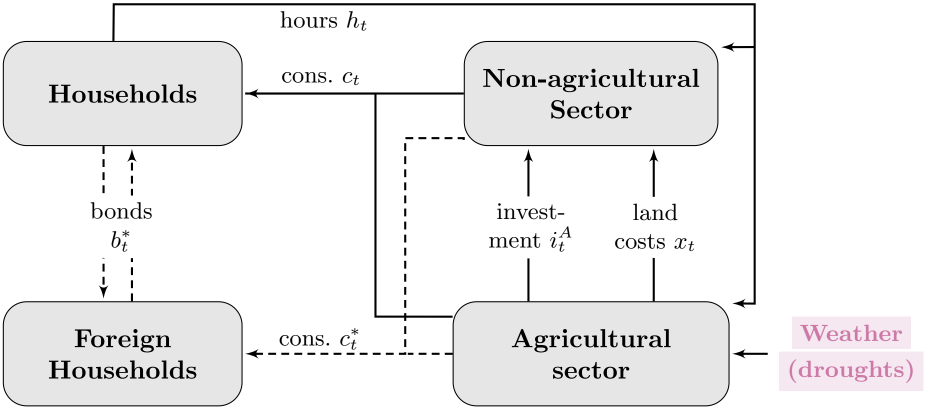


Figure 2: The Model.

Agricultural sector and the weather

- The weather follows an univariate stochastic exogenous process:

$$\log(\varepsilon_t^W) = \rho_W \log(\varepsilon_{t-1}^W) + \sigma_W \eta_t^W, \qquad \eta_t^W \sim \mathcal{N}(0,1) \tag{3}$$

  where $\varepsilon_t^W > 1$ features a **drought**.

- Each farmer $i \in [n, 1]$ has a **land endowment ℓ_{it}** whose time-varying productivity (or efficiency) writes:

$$\ell_{it} = (1 - \delta_\ell)\, \Omega\left(\varepsilon_t^W\right) \ell_{it-1} + x_{it}, \tag{4}$$

  - $\delta_\ell \in (0,1)$ is the rate of decay of land efficiency;
  - x_{it} are intermediate goods to maintain land efficiency (crops, water, fertilizers...);
  - $\Omega\left(\varepsilon_t^W\right)$ is a **weather damage function** (discussed after).

Agricultural sector and the weather (1/3)

- We opt for a simple functional form for this **damage function**:

$$\Omega\left(\varepsilon_t^W\right) = \left(\varepsilon_t^W\right)^{-\theta}, \tag{5}$$

  where θ is the **elasticity of land productivity** with respect to the weather variations.

- Following IAMs models pioneered by Nordhaus (1991), the damage function bridges the weather with economic conditions.
- To avoid concerns from Pindyck (2017):
  1. Our setup is linear (i.e., we don't exploit the non-linearity of the damage function).
  2. θ is estimated agnostically (through a very diffuse prior).

Agricultural sector and the weather (2/3)

- **Profits of the farmer**:

$$d_{it}^{A} = p_t^A y_{it}^A - p_t^N \left(i_{it}^A + S\left(\varepsilon_t^i \frac{i_{it}^A}{i_{it-1}^A} \right) i_{it-1}^A \right) - w_t^A h_{it}^A - p_t^N v\left(x_{it}\right),$$

- For the **land cost function** $v\left(x_{it}\right)$, we opt for an unopiniated form:

$$v\left(x_{it}\right) = \frac{\tau}{1+\phi} x_{it}^{1+\phi}$$

$\tau > 0$: scale parameter; ϕ: **elasticity of intermediate input to land**:

  - $\phi > 0$ land costs exhibits increasing returns, $\phi = 0$ linear returns and $\phi < 0$ decreasing returns.
  - Data favors $\phi \geq 0$ (as weather shocks generate recessions).

Agricultural sector and the weather (3/3)

- Lastly, the optimization of profits is given by:

$$\max_{\left\{h^A_{it}, i^A_{it}, k^A_{it}, \ell_{it}\right\}} E_t \sum_{\tau=0}^{\infty} \left\{\Lambda_{t,t+\tau}\, d^A_{it+\tau}\right\}$$

$$s.t.\ y^A_{it} = \varepsilon^Z_t\, \ell^{\omega}_{it-1} \left[\left(k^A_{it-1}\right)^{\alpha} \left(\kappa_A h^A_{it}\right)^{1-\alpha}\right]^{1-\omega}$$

$$s.t.\ i^A_{it} = k^A_{it} - \left(1-\delta_K\right) k^A_{it-1}$$

- FOC on land ℓ_{it}:

$$\underbrace{p^N_t\, v'\left(x_{it}\right)}_{\text{current marginal land cost}} = \underbrace{E_t \left\{\Lambda_{t,t+1} \left[\omega p^A_{t+1} \frac{y^N_{it+1}}{\ell_{it}} + \left(1-\delta_\ell\right) \Omega\left(\varepsilon^W_{t+1}\right) p^N_{t+1}\, v'\left(x_{it+1}\right)\right]\right\}}_{\text{expected marginal gains}}$$

Estimation

		Prior distributions			Posterior distribution	
		Shape	Mean	Std.	Mean	[5%:95%]
σ_H	Labor disutility	$\mathcal{B}$	2	0.75	1.87	*[1.32:2.40]*
b	Consumption habits	$\mathcal{B}$	0.7	0.10	0.82	*[0.74:0.90]*
ι	Labor sectoral cost	$\mathcal{G}$	2	1	2.32	*[1.36:3.31]*
κ	Investment cost	$\mathcal{N}$	4	1.50	1.83	*[0.77:2.91]*
μ	Subst. by type of goods	$\mathcal{G}$	1.5	0.8	4.93	*[3.53:6.26]*
μ_N	Subst. home/foreign	$\mathcal{G}$	1.5	0.8	1.91	*[0.86:2.94]*
μ_A	Subst. home/foreign	$\mathcal{G}$	1.5	0.8	0.41	*[0.26:0.56]*
ϕ	Land expenditures cost	$\mathcal{G}$	1	0.60	0.76	*[0.02:1.51]*
θ	Land-weather elasticity	$\mathcal{U}$	0	10	8.62	*[2.3:15.78]*
	Marginal log-likelihood				-1012.83	

Table 1: Prior and posterior distributions of structural parameters.

Weather shock propagation

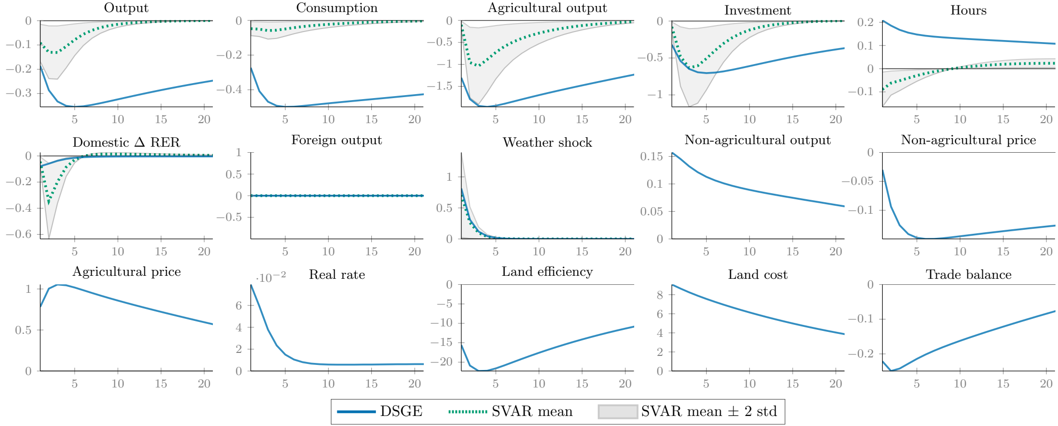


Figure 3: System response to an estimated weather shock η_t^W (pp dev ss).

Variance decomposition

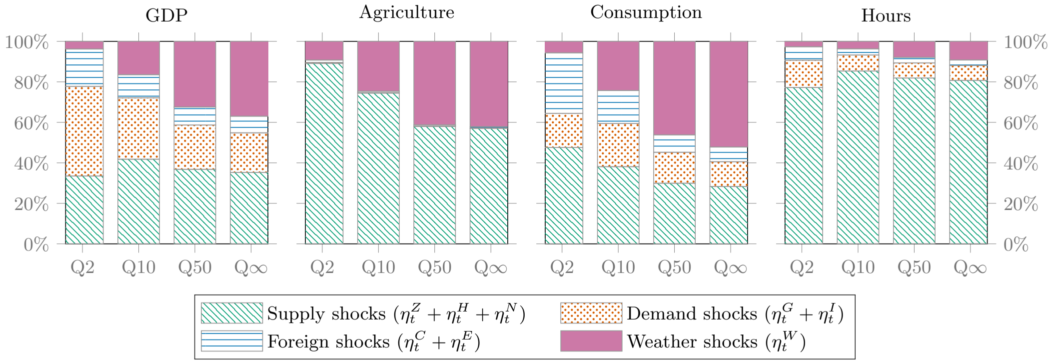


Figure 4: Forecast error variance decomposition at the posterior mean for different time horizons (one, ten, forty and unconditional) for four observable variables.

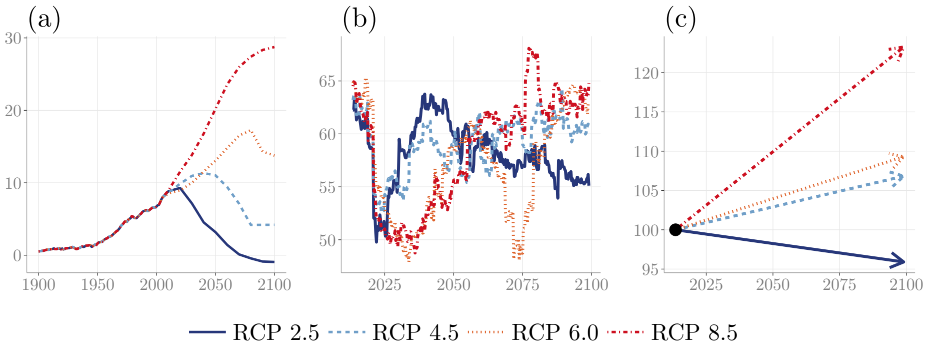
Climate change and Business Cycles

> "A change in the state of the climate that can be identified (*e.g.*, by using statistical tests) by changes in the **mean and/or the variability** of its properties, and that persists for an extended period, typically decades or longer
> IPCC (2014)"

- Climate is supposed to be stationary in our framework: our set-up is irrelevant for analyzing changes in **mean climate values**.
- However, it allows for changes in the **variance of climate**.

Climate change and business cycles (1/2)

- How much is the weather variance expected to increase?



Notes: (a) represents historical CO_2 emissions as well as their projections up to 2100 under each scenario. The estimation of the standard errors of projected precipitations σ_t^W for each representative concentration pathway is represented in panel (b). Their linear trend from 2013 to 2100 is depicted in panel (c).

Climate change and business cycles (2/2)

		1994-2016	2100 (projections)			
		Benchmark	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
sd(η_t^W)	**Weather shock**	100	95.90	106.82	109.30	123.25
sd(Y_t)	GDP	100	99.82	100.15	100.23	100.72
sd(Y_t^A)	Agriculture	100	96.89	102.54	103.86	111.53
E($\mathcal{W}_t$)	**Welfare**	-158.02	-158.00	-158.04	-158.06	-158.13
λ (%)	**Welfare cost**	0.4023	0.3562	0.4417	0.4623	0.5873

Table 2: Changes in Standard-Errors of Simulated Observables Under Climate Change Scenarios.

5. Opening remarks

Opening remarks (1/2)

The analysis of weather shocks can be seamlessly integrated into the existing macroeconomic modelling frameworks used by central banks and policymakers.

- **SVAR Integration:**
  - **The identification strategy** used in this paper—a Cholesky decomposition with exogenous weather shocks identified at business cycle frequencies—**can be directly embedded into standard SVAR models** of any central bank.
  - This approach **requires minimal adjustments to existing forecasting tools**, making it a pragmatic option for central banks seeking to **monitor the impact of climate-related shocks on economic fluctuations**.

Opening remarks (2/2)

- **DSGE Integration:** On the structural side, **the framework can be extended to enrich baseline DSGE forecasting models**:
  - By incorporating a simple **agricultural sector affected by weather shocks**, we can quantify their contribution to aggregate fluctuations and assess their impact on *GDP-at-risk*.
  - The model is implemented in Dynare and can be adapted to various settings, with or without nominal rigidities, providing **flexibility** for different institutional needs.
  - Fast solution for **assessing the variance effects of climate change**.

Both approaches (DSGE/VAR) are highly **modular** and can be tailored to the specific objectives of the NGFS macroeconomic workstream. Whether for **short-term forecasting** or **long-term risk assessment**, this framework offers a robust and operational tool to evaluate the macroeconomic implications of weather shocks.

6. Appendix

References I

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Households (1/2)

There are j households maximizing welfare index:

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left[\frac{1}{1-\sigma_C} C_{jt+\tau}^{1-\sigma_C} - \frac{\chi}{1+\sigma_H} h_{jt+\tau}^{1+\sigma_H} \right] C_{t-1+\tau}^{b\sigma_C}, \tag{6}$$

With an imperfect substitutability of labor supplies between the agricultural and non-agricultural sectors:

$$h_{jt} = \left[\left(h_{jt}^{N} \right)^{1+\iota} + \left(h_{jt}^{A} \right)^{1+\iota} \right]^{1/(1+\iota)}. \tag{7}$$

And real budget constraint:

$$\sum_{s=N,A} w_t^s h_{jt}^s + r_{t-1} b_{jt-1} + rer_t r_{t-1}^{*} b_{jt-1}^{*} - T_t \geq C_{jt} + b_{jt} + rer_t b_{jt}^{*} + p_t^N rer_t \Phi(b_{jt}^{*}). \tag{8}$$

Households (2/2)

- The CES consumption bundle between non-agricultural and agricultural goods is determined by :

$$C_{jt} = \left[(1-\varphi)^{\frac{1}{\mu}}(C_{jt}^{N})^{\frac{\mu-1}{\mu}} + \left(\varphi\varepsilon_{t}^{A}\right)^{\frac{1}{\mu}}(C_{jt}^{A})^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}, \tag{9}$$

with $P_t = [(1-\varphi)(P_{C,t}^{N})^{1-\mu} + \varphi(P_{C,t}^{A})^{1-\mu}]^{1/(1-\mu)}$.

- In addition, each C_{jt}^{N} and C_{jt}^{A} are themselves sub-indexes between home and foreign goods:

$$C_{jt}^{s} = \left[(1-\alpha_s)^{\frac{1}{\mu_S}}(c_{jt}^{s})^{\frac{(\mu_S-1)}{\mu_S}} + (\alpha_s)^{\frac{1}{\mu_S}}(c_{jt}^{s*})^{\frac{(\mu_S-1)}{\mu_S}}\right]^{\frac{\mu_S}{(\mu_S-1)}}, \ s = N, A$$

with $P_{C,t}^{s} = \left[(1-\alpha_s)(P_{t}^{s})^{1-\mu_s} + \alpha_s(e_t P_{t}^{s*})^{1-\mu_s}\right]^{1/(1-\mu_s)}$.

Non-agricultural sector

- There is a continuum of firms indexed by $i \in [0, n]$ maximizing profits:

$$d_{it}^N = p_t^N y_{it}^N - p_t^N \left(i_{it}^N + S\left(\varepsilon_t^i \frac{i_{it}^N}{i_{it-1}^N} \right) i_{it-1}^N \right) - w_t^N h_{it}^N, \tag{10}$$

- Technology:

$$y_{it}^N = \varepsilon_t^Z \left(k_{it-1}^N \right)^{\alpha} \left(h_{it}^N \right)^{1-\alpha}, \tag{11}$$

- Law of motion of physical capital

$$i_{it}^N = k_{it}^N - (1 - \delta_K)\, k_{it-1}^N, \tag{12}$$

Foreign Economy

- Endowment economy with exogenous consumption:

$$\log\left(c_{jt}^{*}\right) = (1-\rho_{*})\log\left(\bar{c}_{j}^{*}\right) + \rho_{*}\log\left(c_{jt-1}^{*}\right) + \sigma_{*}\eta_{t}^{*},$$

- Foreign households solve:

$$\max_{\left\{c_{jt}^{*},b_{jt}^{*}\right\}} \sum_{\tau=0}^{\infty}\beta^{\tau}E_{t}\left\{\mathcal{U}\left(c_{jt+\tau}^{*},c_{t-1+\tau}^{*}\right)\right\},$$
$$s.t.\ : r_{t-1}^{*}b_{jt-1}^{*} = c_{jt}^{*} + b_{jt}^{*}$$

- So that foreign consumption shocks affect the domestic country through imports and the real exchange rate.

Market Clearing (1/3)

- Non agricultural sector clears:

$$
\begin{aligned}
nY_t^N = & (1-\varphi)(1-\alpha_N)\left(\frac{P_t^N}{P_{C,t}^N}\right)^{-\mu_N}\left(\frac{P_{C,t}^N}{P_t}\right)^{-\mu} C_t \\
& + (1-\varphi)\,\alpha_N\left(\frac{1}{e_t}\frac{P_t^N}{P_{C,t}^{N*}}\right)^{-\mu_N}\left(\frac{P_{C,t}^{N*}}{P_t^*}\right)^{-\mu} C_t^* \\
& + G_t + I_t + v\left(x_t\right) + \Phi(b_t^*)
\end{aligned}
$$

where $I_t = nI_t^N + (1-n)\, I_t^A$..

Market Clearing (2/3)

- Agricultural sector clears:

$$(1-n)Y_t^A = \varphi(1-\alpha_A)\left(\frac{P_t^A}{P_{C,t}^A}\right)^{-\mu_A}\left(\frac{P_{C,t}^A}{P_t}\right)^{-\mu} C_t + \varphi\alpha_A\left(\frac{1}{e_t}\frac{P_t^A}{P_{C,t}^{A*}}\right)^{-\mu_A}\left(\frac{P_{C,t}^{A*}}{P_t^*}\right)^{-\mu} C_t^*$$

- Total production reads as:

$$Y_t = np_t^N Y_t^N + (1-n)\, p_t^A Y_t^A$$

Market Clearing (3/3)

- The law of motion of motion of foreign debt is given by:

$$b_t^* = r_{t-1}^* \frac{rer_t}{rer_{t-1}} b_{t-1}^* + tb_t, \tag{13}$$

- And the trade balance reads as:

$$\begin{aligned} tb_t = {} & p_t^N \left[nY_t^N - G_t - I_t - v\left(x_t\right) - \Phi(b_t^*) \right] \\ & + p_t^A (1-n) Y_t^A - C_t. \end{aligned}$$

Calibration (1/2)

Variable	Interpretation	Value
β	Discount factor	0.9883
δ_K	Capital depreciation rate	0.025
α	Share of capital in output	0.33
g	Share of spending in GDP	0.22
φ	Share of good in consumption basket	0.15
$\bar{H}^N = \bar{H}^A$	Hours worked	1/3
σ_C	Risk aversion	1.5
$\bar{\ell}$	Land per capita	0.40
ω	Share of land in agricultural output	0.15
δ_ℓ	Rate of decay of land efficiency	0.10
α_N	Openness of non-agricultural market	0.25
α_A	Openness of agricultural market	0.45
χ_B	International portfolio cost	0.007
σ_C^*	Foreign risk aversion	1.5
b^*	Foreign consumption habits	0.7

Table 3: Calibrated parameters.

Calibration (2/2)

Variable	Interpretation	Model	Data
$\bar{C}/\bar{Y}$	consumption-to-GDP	0.56	0.57
$\bar{I}/\bar{Y}$	investment to GDP	0.22	0.22
$400 \times (\bar{r} - 1)$	real interest rate	4.74	4.75
$(1-\varphi)\,\alpha_N + \varphi\alpha_A$	goods market openness	0.28	0.29
$n\bar{Y}^A/\bar{Y}$	farming production-to-GDP	0.08	0.07

Table 4: Steady state ratios (empirical ratios are computed using data between 1990 to 2017).

Estimation (1/3)

The model is estimated using Bayesian techniques which combine likelihood estimation with prior information via Dynare.

- We estimate 6 sequences of shocks
- We estimate 21 structural parameters
- Parameters related to weather conditions are estimated agnostically with diffuse prior.

Estimation (2/3)

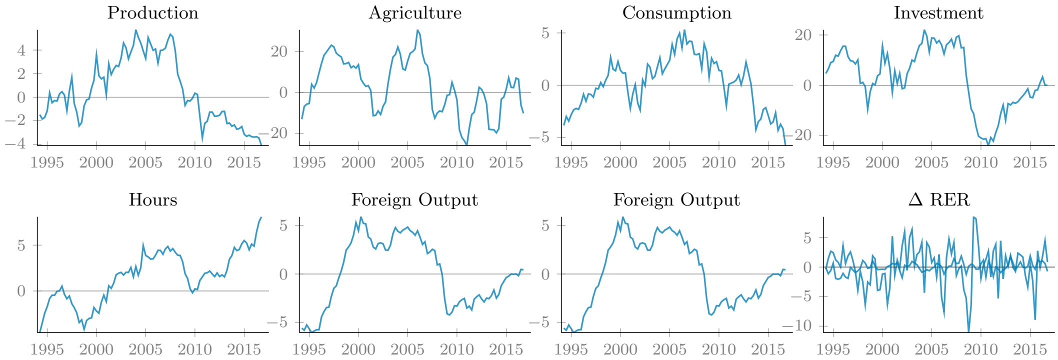

Figure 5: Observable variables used to estimate the DSGE model.

Estimation (3/3)

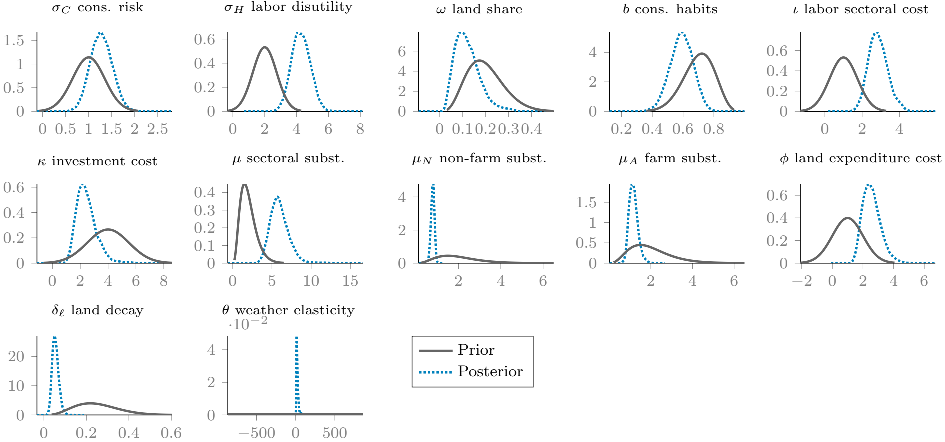

Figure 6: Prior and posterior distrib. of structural params for New Zealand (excluding shocks).

Do weather shocks matter?

	No Weather-Driven Business Cycles $\mathcal{M}(\theta = 0)$	Weather-Driven Business Cycles $\mathcal{M}(\theta \neq 0)$
Prior probability	1/2	1/2
Laplace approximation	-1016.853	-1012.835
Posterior odds ratio	1.000000	55.626
Posterior model probability	0.018	0.982

Table 5: Prior and posterior model probabilities.