What are the drivers of the Swedish sustainable development path?

New evidence from Bayesian Dynamic Linear Models

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joint work with **Jesper Stage, Magnus Lindmark, Huong Nguyen**

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- Genuine Savings (GS) indicators is a forward-looking measure which has been considered as the leading economic indicator of changes in future well-being.
  - However, there are different forms of GS affect the stream of well-being over time.
  - In this study, we extend Genuine Savings (GS) indicators to account for a wider range of impacts on natural and human capital and study Swedish long-term sustainability.

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- The prediction power of GS can not be constant due to measurement error.
  - In this study, we uncover the dynamic effect of GS by introducing Dynamic Linear Model (DLM).
  - Apply Bayesian approach to estimate the dynamic process.

AGENDA

THEORETICAL FRAMEWORK

Consider optimal social planer problem (see Hartwick 1990),

$$W = \int_0^{\infty} U(C, B)e^{-rs}ds \tag{1}$$

where social welfare W be the present value of utility on the optimal path. It is assumed that the utility of consumers U is a function of consumption C and environmental services B and r is a fixed pure rate of time preference.

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$$GS = \sum_i p_i \dot{K}_i \tag{3}$$

where K_i is the stock of assets in the economy and p_i is the shadow price. (e.g physical assets, human capital, depletion of natural resources, pollutants,..)

PVC

Following WorldBank 2005, the current change in total wealth per capita is defined as,

$$W_0 = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left(\frac{C_t}{N_t} - \frac{C_{t-1}}{N_{t-1}} \right), \tag{4}$$

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PVC_t is the present value of changes in future consumption per capita at time t (Ferreira, Hamilton, and Vincent 2008)

$$PVC_t = \sum_{v=t}^{t+T} \left(\frac{C_{v+1}/N_{v+1} - C_v/N_v}{\prod_{j=t}^{v} (1 + \rho_j - \gamma_j)} \right) \tag{5}$$

where ρ_j is the consumption discount rate at time j and γ_j is the population growth rate at time j.

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- $GSWPOP_t$ = GS_t - wealth dilution per capita

see Lindmark and Acar 2013 for details.

TEST FOR THE PREDICTION OF GS

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Ferreira and Vincent 2005 established a theoretical framework for testing the properties of GS under three hypotheses.

- *Hypothesis 1.* $\beta_0 = 0$ and $\beta_1 = 1$
- *Hypothesis 2.* $\beta_1 > 0$ and $\beta_1 \to 1$ as the net investment term includes more types of capital.
- *Hypothesis 3.* $\beta_1 > 0\,.$

Dynamic Linear Models

$$y_t = \alpha_t + x_t\beta_t + \sigma\epsilon_t \tag{8}$$

$$\alpha_t = \alpha_{t-1} + \sigma_\alpha\xi_t \tag{9}$$

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where

- y_t is PV of changes in future consumption per capita over T year horizon PVC_t.
- x_t is one of the GS indicators.

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Model assumptions:

- $\epsilon_t \sim iid.N(0,1)$ and $\xi_t, \eta_t \sim iid.N(0,1)$.
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- Use Rstan package to estimate model with a inverse gamma prior distribution (IG) for $\sigma^2 \sim IG(0.001, 0.001)$, $\sigma_\alpha^2 \sim IG(0.001, 0.001)$ and $\sigma_\beta^2 \sim IG(0.001, 0.001)$.

Data

- Time: Swedish series from 1850 to 2000
- Dependent variables
  - $PVC20$: PV of changes in Consumption from 1850 to 1990
  - $PVC50$: PV of changes in Consumption from 1850 to 1960
- Explanatory variables
  - $NETPINV, GREENINV, GS, GSWPOP$: GS measurements from 1850 to 2000
  - $GREENTFP20, GSTFP20$: GS measurements from 1850 to 1980
  - $GREENTFP30, GSTFP30$: GS measurements from 1850 to 1970

PVC

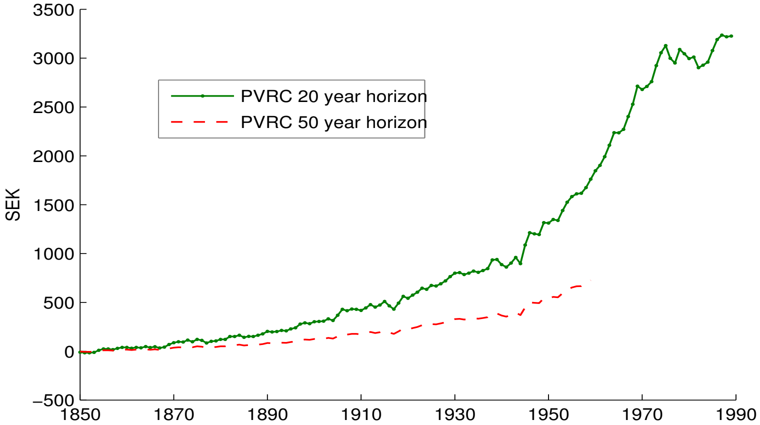

Figure: Present value of future changes in real consumption per capita, 3% per annum discount rate (SEK)

NETPINV AND GS

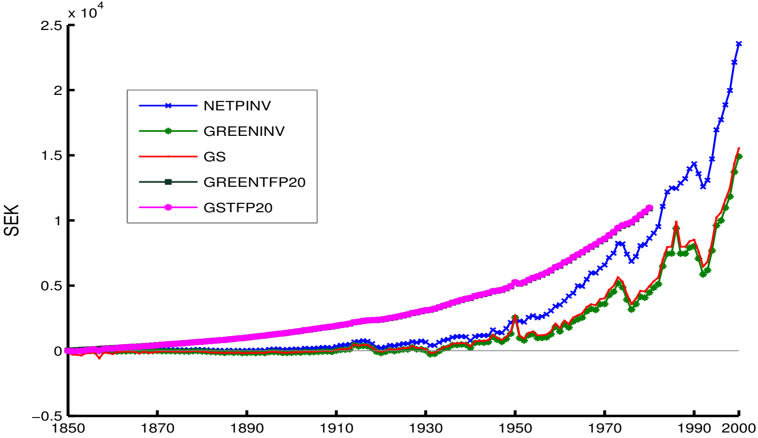

Figure: Net investment and GS adjust series per capita (Fixed 1912/13 prices)

BAYESIAN INFERENCE OF DLMS FOR $PVC20$

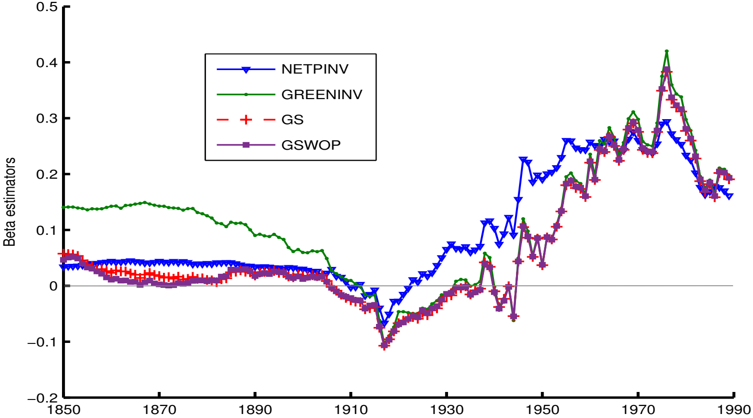

Figure: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC20$.

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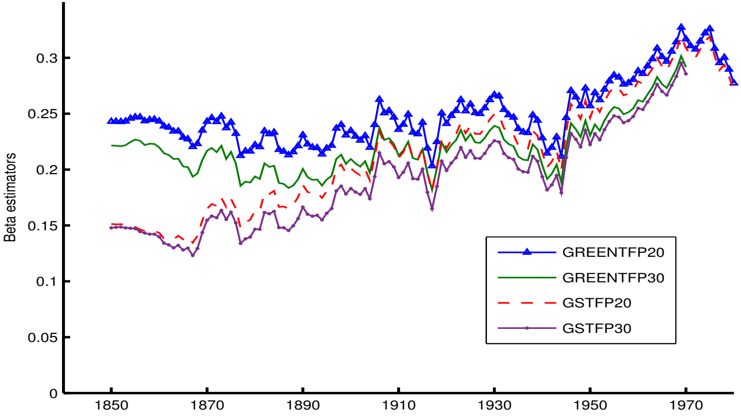


Figure: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC20$.

Bayesian inference of DLMs for $PVC50$

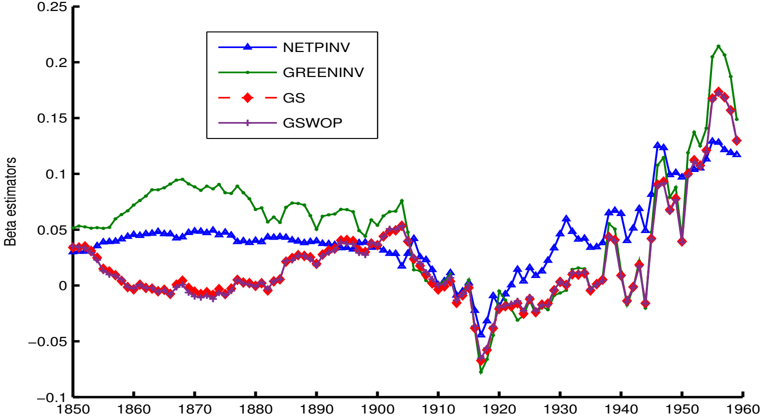
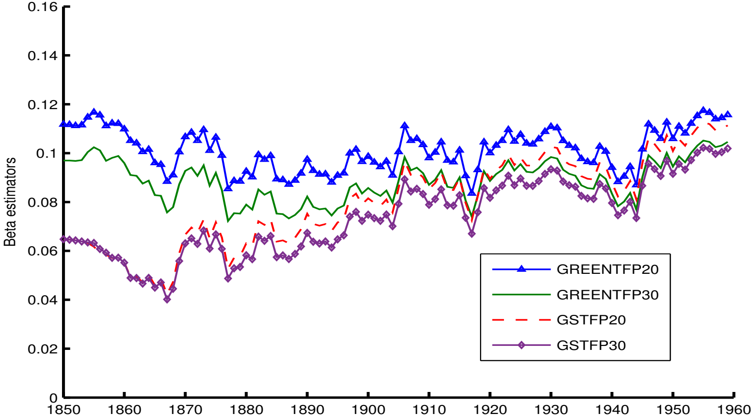


Figure: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC50$.

Bayesian inference of DLMs for $PVC50$



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Conclusion

- Extended the measure of GS accounting for natural resource, human capital and technological progress.
- Applied DLM to analyze the dynamic effect of GS to Swedish well-being.
- The prediction power of GS is improved by the technological progress.
- The measurement error of GS is reduced and β_1 is decreasingly biased toward zero.

Thank you

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Bayesian estimation of DLM models

$$PVC20_t = \alpha_t + GS_t\beta_t + 1.902\epsilon_t \tag{11}$$

$$\alpha_t = \alpha_{t-1} + 29.429\xi_t \tag{12}$$

$$\beta_t = \beta_{t-1} + 0.038\eta_t \tag{13}$$

y_t	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50
x_t	NETPINV		GREENINV		GS		GSWPOP	
σ	0.92	0.577	2.109	1.272	1.902	0.831	1.855	0.614
	(1.305)	(0.517)	(1.757)	(0.598)	(1.746)	(0.746)	(1.545)	(0.622)
σ_α	23.365	8.065	29.889	9.178	29.429	9.586	29.482	9.6
	(2.645)	(0.802)	(4.294)	(0.941)	(3.784)	(0.922)	(3.77)	(0.935)
σ_β	0.024	0.019	0.045	0.036	0.038	0.028	0.039	0.028
	(0.004)	(0.003)	(0.011)	(0.006)	(0.008)	(0.004)	(0.008)	(0.004)

Table: Posterior mean of the parameters in the Swedish DLMs for the periods $1850-2000$

Bayesian estimation of DLM models

y_t	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50
x_t	GREENTFP20		GREENTFP30		GSTFP20		GSTFP30	
σ	4.753	1.563	4.299	1.467	4.891	1.696	5.629	1.755
	(2.166)	(0.836)	(2.422)	(0.865)	(2.469)	(0.815)	(1.957)	(0.848)
σ_α	7.978	2.798	7.58	2.739	7.862	2.69	6.752	2.384
	(2.563)	(1.022)	(2.853)	(1.049)	(2.745)	(1.02)	(2.587)	(1.04)
σ_β	0.013	0.008	0.012	0.007	0.013	0.008	0.012	0.007
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

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