Fossil energy in economic growth: A study of the energy direction of technical change, 1950-2012

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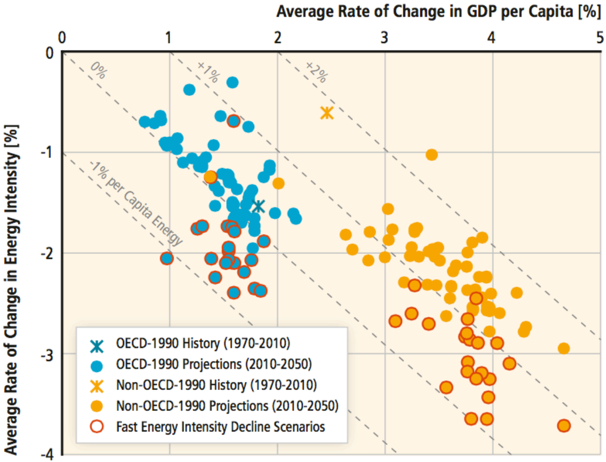
The world economy is supposed to grow.
It is also supposed decouple from fossil fuel use.

Technical change is supposed to play an important role in achieving both goals simultaneously.

To what degree can it?

The question matters....

Technical change plays a huge role in scenarios of future growth and energy use.



Source: IPCC 2014

… but we have no empirically grounded answer

Studies based on direct hypotheses about the energy-output relationship

- 'Energy GDP Nexus' (Ozturk 2010, Payne 2010)
- ‘Environmental Kuznets Curve’ for CO_2 (Stern 2004, Yang 2014);

Studies based on economic growth theory

- Based on price changes and relative factor supplies (Jorgenson 1984, Fisher-Vanden et al. 2008, Hassler et al. 2012, Acemoglu et al. 2012)
- Based on biophysical considerations with economies of scale (Ocampo et al. 2008, Rezai et al. 2013)

Results of the present study in a nutshell

Based on a biophysical perspective on long-run technical change in the world economy, I find:

- Stylized fact: the rate of change of energy productivity is constant over a wide range of labor productivity growth rates.
- Exceptions in 1980s and 1990s correlate with the aftermath of the OPEC oil crises and the transition of formerly planned economies.
- Implication 1: growth models should be able to satisfy this stylized fact.
- Implication 2: Fast national economic growth will likely require a cheap, abundant energy supply.

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1. Motivation & results preview
2. Method & data
3. Results
4. Discussion & and research needs

Method: A simple, long-run production approach

The role of fossil energy in economic growth is investigated based on the relationship between rate and direction of technical change with respect to fossil energy – in the long run for all countries.

To operationalize this approach, an increasing returns to scale-based model of technical change is used (without price-induced technical change).

Labor productivity growth represents the **rate**, and changes in the fossil energy-labor ratio represent the **direction** of technical change.

Method: Specifying a relationship

Expand realized fossil energy productivity with labor:

$$\frac{X}{F} \equiv \frac{X}{L} \times \frac{L}{F} \qquad \Leftrightarrow \qquad \phi \equiv \lambda \times e^{-1} \tag{1}$$

- realized fossil fuel productivity: $\phi := X/F$,
- realized labor productivity: $\lambda := X/L$,
- fossil energy-labor ratio: $e := F/L$.

Proportional growth rates follow as

$$\hat{\phi} \equiv \hat{\lambda} - \hat{e} \; . \tag{2}$$

Theory: per increasing returns to scale, assume $\hat{e}$ (direction of technical change), is an increasing function, f, of $\hat{\lambda}$ (rate of technical change)

$$\hat{e} = f(\hat{\lambda}) \; . \tag{3}$$

Then changes in the energy intensity of the economy follow via accounting identity in (2).

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Data Sources

A panel of national and regional labor productivity $\hat{\lambda}$ fossil energy-labor ratio, $\hat{e}$ compound annual growth rates, 1950-2012.

- Primary, non-residential fossil fuel consumption: UN (1950-68), IEA (1971-2012)
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Compound annual $\hat{\lambda}$ and $\hat{e}$ cross sections: preview 2000-12

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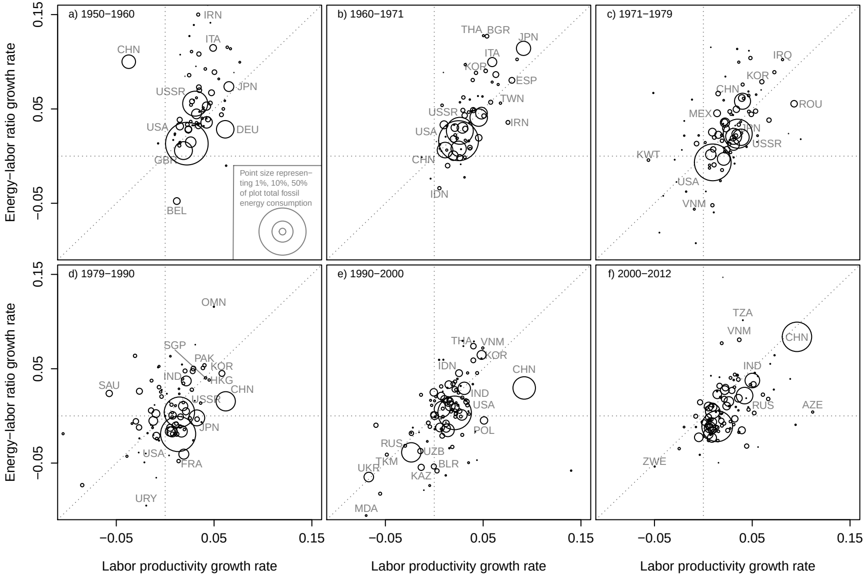
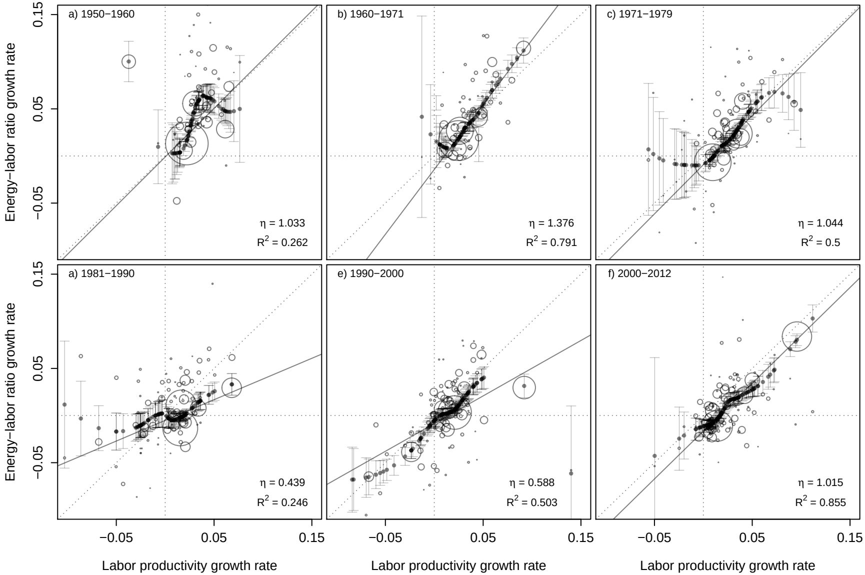


Fits to compound annual $\hat{\lambda}$ and $\hat{e}$ cross sections



Regions and countries

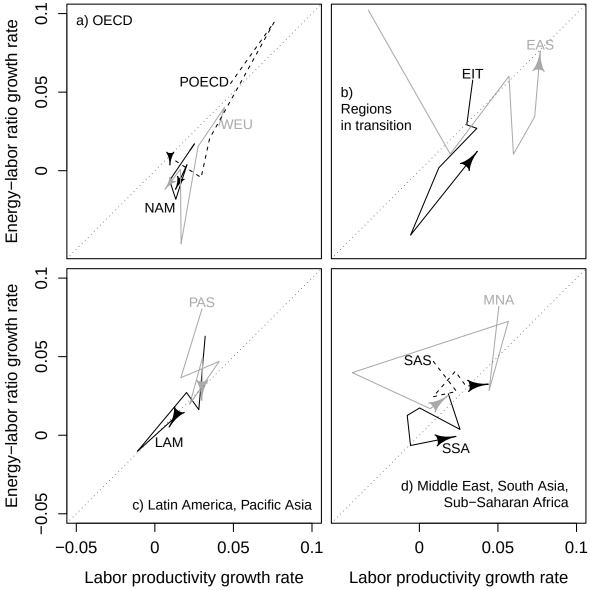


Table: Panel country and time fixed effects estimates.

	World	OECD	non-OECD	EIT	$World_{-1980s}$
η	0.727 **	0.868 **	0.695 **	0.627 **	0.808 **
	(0.067)	(0.151)	(0.080)	(0.137)	(0.079)
1950s	0.048**	0.030 **	0.055 **	0.073 **	0.045**
	(0.006)	(0.007)	(0.008)	(0.018)	(0.006)
1960s	0.022**	0.033 **	0.016 *	0.042 *	0.021 **
	(0.006)	(0.007)	(0.008)	(0.018)	(0.006)
1970s	0.014*	0.015 *	0.013	0.011	0.014
	(0.005)	0.006	(0.007)	(0.015)	(0.005)
1980s	0.007	0.009	0.006	0.004	
	(0.005)	(0.005)	(0.007)	(0.016)	
1990s	-0.003	0.009	-0.007	-0.034 *	-0.002
	(0.005)	(0.005)	(0.006)	(0.011)	(0.005
R-squared	0.404	0.693	0.388	0.669	0.420
Adj R-squared	0.308	0.542	0.288	0.395	0.302
N	550	138	412	88	455

** significant at the 99.9% confidence level.

* significant at the 95% confidence level.

Recap and implications: the global level

- Rate and direction of technical change linked. Energy using technical change worldwide near unit elasticity, but no 'trade-off'
- Clear pattern (thanks to longer dataset) but for two shocks – oil price crisis and transition of planned economies
- Growth models should be able to accomodate this 'stylized fact'

Recap and implications: the national level

- Fast rates of technical progress were highly energy-using throughout
- Growth requires cheap, abundant energy supply
- Want to accelerate access to low-carbon energy sources (no effect on direction of technical change with total energy - see appendix)

Research needs

- Build models that 'explain' this stylized fact
- Simulate IPCC models with this additional constraint
- Investigate in how far trade-linkages: embodied energy net exports, change/confirm this relationship

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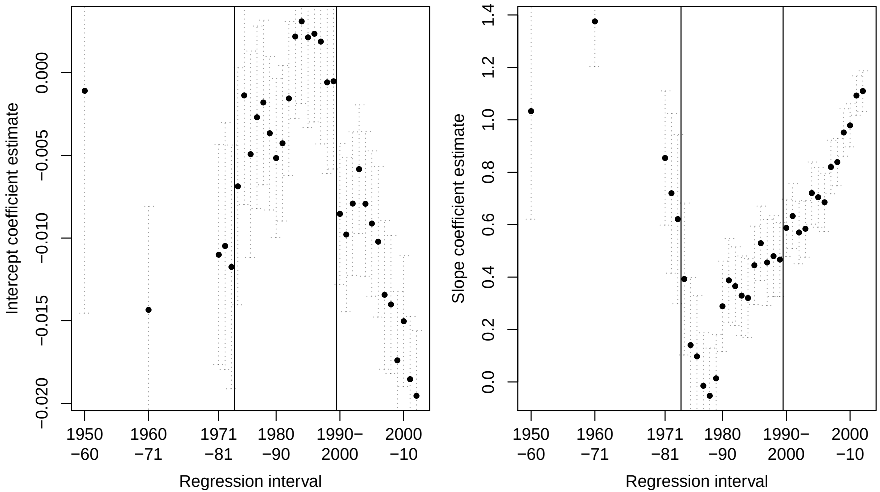
Appendix 1: Data Summary

Table: Regional growth rate in percent. Fossil fuel productivity (ϕ), labor productivity (λ), fossil energy-labor ratio (e).

Region	1950–1971			1971–2012		
	$\hat{\lambda}$	$\hat{e}$	$\hat{\phi}$	$\hat{\lambda}$	$\hat{e}$	$\hat{\phi}$
North America	2.4	1.5	0.9	1.4	-1.0	2.4
Western Europe	4.3	3.5	0.8	1.6	-0.6	2.2
Pacific OECD	6.3	7.6	-1.3	2.0	0.8	1.2
Economies in Transition	3.2	4.3	-1.1	1.9	0.4	1.5
Latin America	2.8	3.8	-1.0	0.6	0.5	0.1
Sub-Saharan Africa	2.4	1.4	1.0	0.3	-0.1	0.4
Middle East & North Africa	4.7	5.4	-0.7	0.7	3.6	-2.9
East Asia	-0.4	6.6	-6.2	6.6	4.3	2.3
Pacific Asia	2.3	5.7	-3.4	3.1	4.0	-0.9
South Asia	1.7	3.7	-2.0	2.7	4.0	-1.3

Appendix 2: Rolling cross-section regression



Appendix 3: Low carbon energy effect on $\hat{e}$

Dep. Variable	Fossil $\hat{e}_{2000-12}$	Total $\hat{e}_{2000-12}$
$\hat{\lambda}$	1.029*	1.023*
	(0.038)	(0.037)
ρ	-1.394*	-0.226
	(0.287)	0.284
Intercept	-0.016*	-0.016*
	(0.002)	(0.002)
N	112	112
R^2	0.858	0.870
Log Lik	222.010	240.896

* implies significance at 1 percent level.