

The bias of innovation and the macro dynamics of growth:

Another 'parable' of the 19th century U.S. economy's development

By

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ABSTRACT

The microeconomic foundations of the theory of localized technological change due to learning that is 'neutral' in its implications for factor use are understood to give rise to trajectories of innovation that can be path dependent and non neutral ("biased") in their global factor saving implications. This analytical construct, elaborated by David's (1975) examination of sectoral processes of innovation and diffusion, and recently adapted by Allen (2009) as an appropriate paradigm of technical change in the British industrial revolution, also inspires an illuminating "parable" of macroeconomic growth in the U.S. economy of the nineteenth century. Aggregate data on real GDP, factor service inputs, factor shares and nominal and real gross domestic savings rates are used to estimate the parameters of a structural model in which global capital deepening innovations generate rising labor productivity and savings rates during an extended "traverse" towards a more 'roundabout' mode of production. The importance of free immigration is underlined in this story, as it effects in stabilizing the incipient rise of real wages served to increase the shift in the functional distribution of real GDP that underlay the accommodating rise of the real growth savings rate.

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OUTLINE

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2. “Locally neutral” learning-by doing and the potential for the emergence of a globally biased trajectory of technological advance
3. The empirical case for the capital-deepening bias of innovations as a major source of 19th c. US aggregate real labor productivity growth
4. Structural models of (real) supply and demand in the “loanable funds” market with, and without Harrod labor-saving biased innovations
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5. The “new parable” of 19th century American macroeconomic growth, its predecessors, and some implications

§ 1: A heuristic leap: from micro-engineering models of technical change, to 'parables' of aggregate economic growth

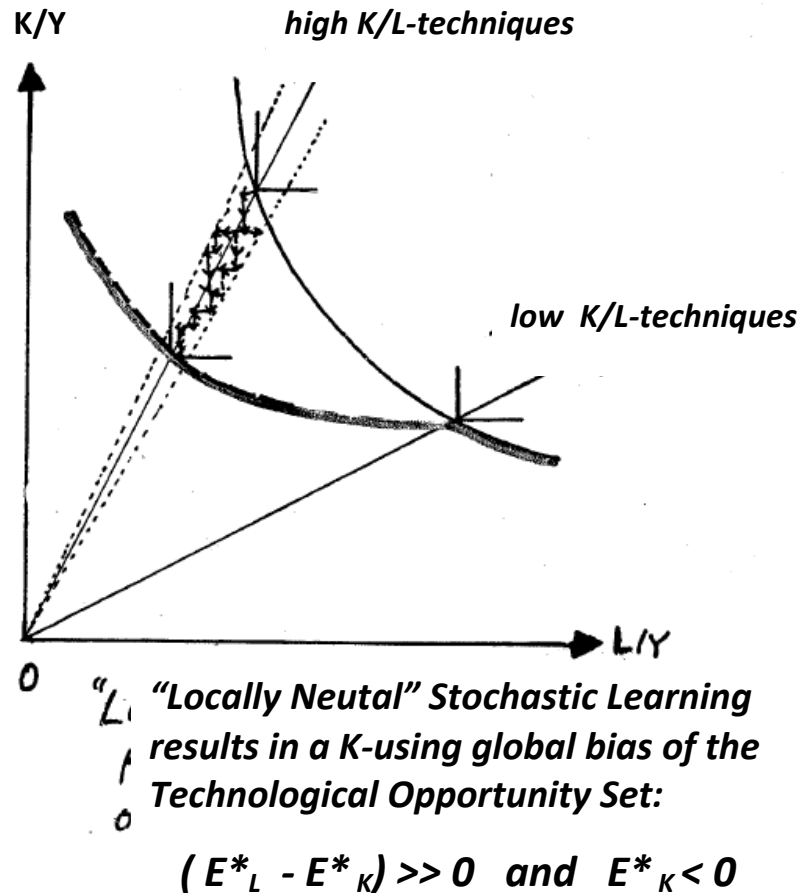
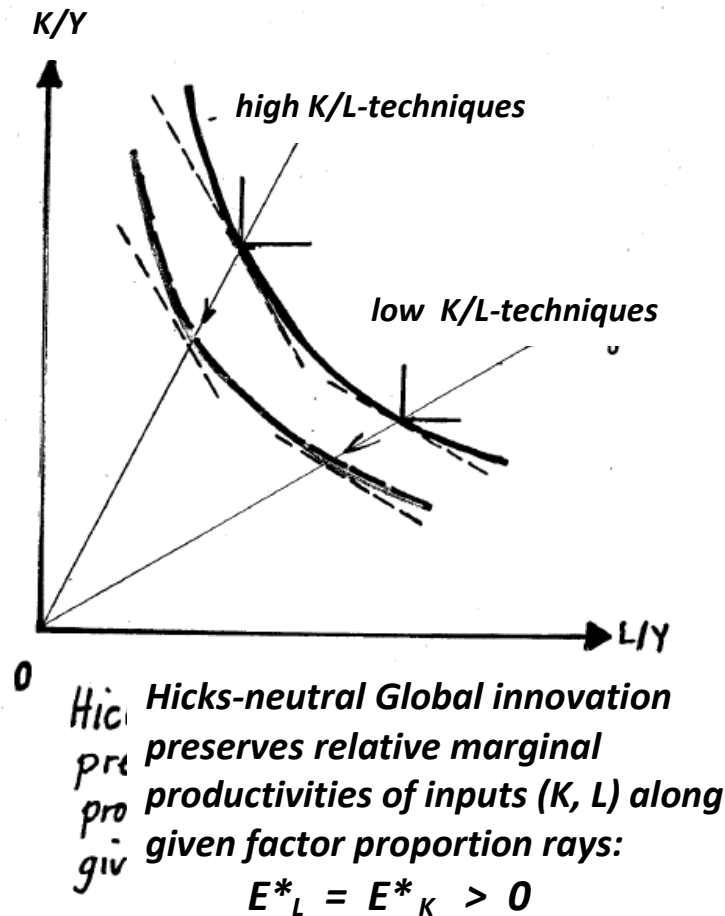
David (1977): It seems inevitable that macroeconomic storytellers—whether concerned with the demand side of the drama or with the supply side, as I am in this paper—should take as their license the famous aphorism of Voltaire: "History is a fable agreed upon."

Whereas discussions of economic development from the macroeconomic vantage point virtually oblige the participants to traffic in fables, it does not follow that all fables should be accepted as having equal claim to attention.

The storyteller's art is to select among the many conceivable allegorical plots those that do rough justice to the particular historical realities with which the audience has been acquainted, while furnishing useful "moral lessons" in the form of pragmatic inspiration for future research, if not general instructions for the guidance of current policymaking.

I intend to continue employing the aggregate production function metaphor for the same purposes here. To do so, one need not harbor any delusions that this fabulous neoclassical beast's behavior must be mimicked by the workings of a "real world" economy.

§ 2: “Locally neutral” learning-by doing at the micro-level creates potential for the path dependent emergence of a globally biased trajectory of technological advance



Remark: Available process techniques are here characterized by fixed coefficients in their aggregate unit input requirements, the aggregates reflecting the mix of engineering sub-systems in the technique. Technical interrelatedness (‘super-modularities’) among sub-systems constrain the characteristic K/L to remain within the tight cone of the original system design.

§ 3 : The empirical case for the capital-deepening bias of innovations as a major source of aggregate real labor productivity growth . . .

3.1: Contemporary economic observers, cliometricians, and the increasing ‘roundaboutness’ of the 19th century capitalist mode of production

● ***Pertinent contemporary perceptions of a capital-deepening bias in technological change:***

Jevons, Wicksell, Bohm-Barwerk and J.B. Clark (in the U.S) all saw “the progress of invention” as achieving greater efficiencies in the use of labor by increasing the “roundaboutness” of production in the economy, and taking the form of greater degrees of specialization of production, machinery and labor in an ever more intricate system of exchange and cooperation. More capital goods were thus being used to make capital goods and consumption goods. This emphasized the role of enlargement of scale and specialization in realizing the potential of new knowledge, and in encouraging the substitution of capital for labor. Frank W. Taussig (1897) echoed their views and those expressed by Henry Sidgwick (1887) when he wrote that this trajectory of progress was *historically situated*, and might not continue:

In the past, those inventions and discoveries which have most served to put the powers of nature at human disposal have indeed often taken the form of greater and more elaborate preparatory effort. The railway, the steamship, the textile mill, the steel works, the gas works and electric plant – in all of these, invention has followed the same general direction. But that it will do so in the future, or has always done so in the past, can by no means be laid down as an unfailing rule.

§ 3: The empirical case for the capital-deepening bias of innovations as a major source of aggregate real labor productivity growth . . .2 -->

3.1 Contemporary economists' perceptions of a capital-deepening bias in technological change have received a measure of econometric support from subsequent "Cliometric" research on US manufacturing industries and the aggregate domestic economy during 1840-1900

- David & van der Klundert (1965), David (1975), Cain & Patterson (1981), James & Skinner (1985), and others: **found evidence consistent with the existence of a *Harrod* labor-saving bias of technical change from the relationship between time-series changes in capital-intensity (K/L) and in ratio of factor shares (θ_L/θ_K) --- or, equivalently, the ratio of real wages to the real rental rate of capital (w/r).**
- This line of research involved fitting parameters of CES and translog production function specifications, that held constant the elasticity of substitution between labor and capital inputs, imposed constant returns to scale, and expressed the inputs efficiency units, by introducing by factor-specific efficiency indexes that could change at different rate in time:

$$Y(t) = Y\{L(t) \cdot E_L(t), K(t) \cdot E_K(t), R(t) \cdot E_R(t), H(t) \cdot E_H(t)\}$$

where the sum of the input elasticities (consistent with f.o.h.) are

$$\epsilon_L(t) + \epsilon_K(t) + \epsilon_R(t) + \epsilon_H(t) = 1, \quad \text{for every } t.$$

3.2: Growth-theoretic accounting, and the magnitude of "traversing effects"

BASIC NEOCLASSICAL GROWTH THEORY and "GROWTH-THEORETIC ACCOUNTING"-- 1

Steady-state growth paths in the Solow (1956) model:

- a) A first-order-homogeneous production function, with technical change restricted to Harrod-neutral

$$Y = F(E_K K, E_L L), \quad \dot{E}_K = 0; \quad \text{or, equivalently}$$

$$\frac{1}{\nu} = F(E_K, (E_L L)/K), \quad \text{where } \nu \equiv K/Y.$$

- b) A fixed net savings rate, s : $S_N = sY$.

- c) Equilibrium in the loanable funds market implies (requires)

$$I_N = S_N,$$

$$\therefore \dot{K}/K = s \frac{Y_N}{K} = s/\nu. \quad \text{This is the "warranted growth rate" of } K.$$

- d) Exogenous growth of labor inputs (L) and labor efficiency due to Harrod-neutral technical change ($\dot{E}_L > 0$) \Rightarrow the "natural" rate of growth,

$$g \equiv (\dot{L}/L + \dot{E}_L/E_L) = \dot{Y}/Y$$

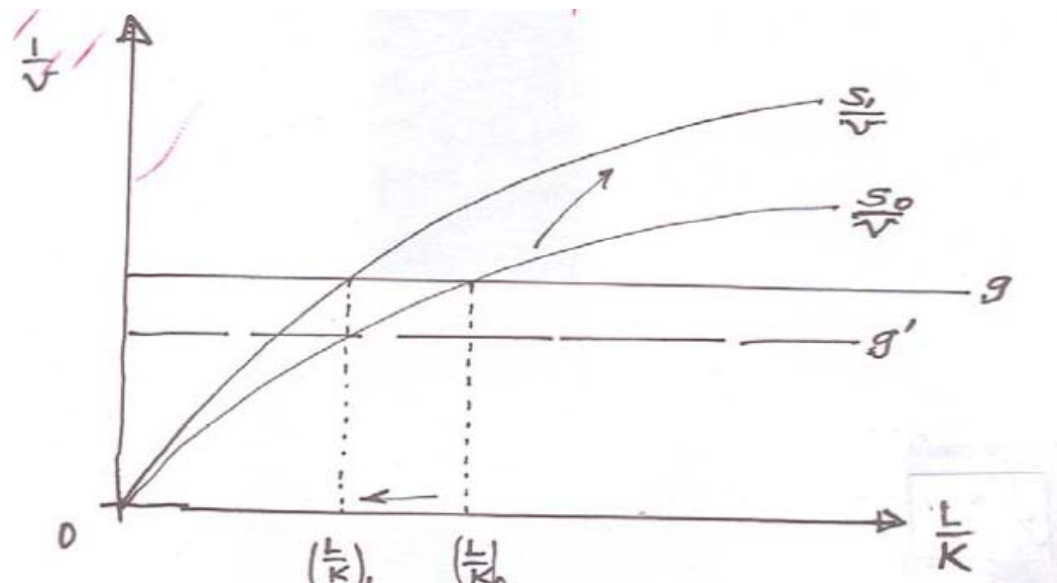
- e) Steady state growth condition: $\frac{\dot{K}}{K} = g$

3.2: Growth-theoretic accounting, and the magnitude of “traversing effects”

BASIC NEOCLASSICAL GROWTH THEORY and “GROWTH-THEORETIC ACCOUNTING”-- 2

Remark 1) Increasing the savings rates leaves the steady-state growth rate of output and the labor productivity growth rate unaltered (if the labor input growth rate is unchanged), but it induces capital-labor substitution in the “traverse” (lowering (L/K)).

Remark 2) With a constant savings rate, in this model, the average productivity of capital ($1/v$) can rise only if the “natural growth rate” decreases (i.e., from g to g'), say, due to a slowing of the labor input growth rate. Capital intensity (K/L) will rise in the traverse.



3.2: Growth-theoretic accounting, and the magnitude of "traversing effects" during '1835' – '1890' [David, "Invention and Accumulation" (1977)]

Trend Intervals	Per annum rates of growth of		Percentage	
	Real product per capita (\dot{y}^*)	Effect of "Traversing" $(\theta_K/(1 - \theta_K))\dot{v}^*$	Relative Contribution of "Traversing" in: \dot{y}^* \dot{Y}^*	
'1800 - 1835'	.0117	.0009	7.7	2.1
'1835 - 1855'	.0106	.0051	48.1	12.3
'1855 - 1890'	.0155	.0055	35.5	13.7
'1890 - 1905'	.0185	.0009	4.9	2.4

Sources and Notes:

Estimates of \dot{Y}^* , $\dot{v}^* = \dot{K}^* - \dot{Y}^*$, θ_K are those given in Table 2.

Population growth rates (per annum) for the four trend intervals in this table are, in consecutive order .0302, .0305, .0241, and .0191. The average annual rates of change given above for \dot{y}^* are discrete time rates computed directly from the underlying estimates of $y = Y/P$ so as to allow for interaction terms.

Note that the per capita growth rate version of equation (5) is:

$\dot{y}^* = g + (\theta_K/(1 - \theta_K))\dot{v}^*$, where g is the per capita analogue of the natural rate G :

$$g = [\dot{E}_L + (\dot{L} - \dot{P})] \left[\frac{\theta_L}{1 - \theta_K} \right] + [\dot{R} - \dot{P}] \left[\frac{\theta_R}{1 - \theta_K} \right]$$

From Table 2 and this Table are found the following components of the average per capita output growth rate for the period 1835-1890:

$$\dot{E}_L \theta_L / (1 - \theta_K) = .003; (\dot{L} - \dot{P}) \theta_L / (1 - \theta_K) = .0043;$$

$$(\dot{R} - \dot{P}) \theta_R / (1 - \theta_K) = .0009; (\dot{v}^* \theta_K) / (1 - \theta_K) = .0054.$$

3.2: Growth-theoretic accounting, and the magnitude of “traversing effects” during ‘1835’-‘1890’ [David, “Tale of Two Traverses” (2004)]

Manhours Productivity (percent per annum)	“Capital-Deepening”	Relative Weight (percent rate per annum)	Effect of “Capital-Deepening”	Percentage Contribution to Labor Productivity Growth Rate
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Frame I: The Nineteenth Century: Tangible Reproducible Capital-Deepening

Periods	$[Y^* - L^*]$	$[K^* - Y^*]$	(θ_K/θ_L)	$(\theta_K/\theta_L)[K^* - Y^*]$	$\frac{(\theta_K/\theta_L)[K^*-Y^*]}{[Y^*-L^*]}$
1800-1835	0.26	0.68	.281	0.193	73.9
1835-1890	0.68	1.21	.487	0.589	86.7
1890-1905	1.37	0.14	.625	0.087	6.3

Note: The entries shown for “1800-1835”, “1835-1890”, “1905-1927” refer, as previously, to the terminal year averages: 1799/1800, 1834/36, 1888/1892, 1903/07, 1925/29; for post-1929 periods the underlying terminal year data are those for 1929, 1966, 1989.

4. Structural models of (real) supply and demand in the “loanable funds” market with, and without Harrod labor-saving biased innovations

4.0 Neoclassical baseline: planned net investment rate is adjusted to a higher planned net savings rate through capital-labor substitution

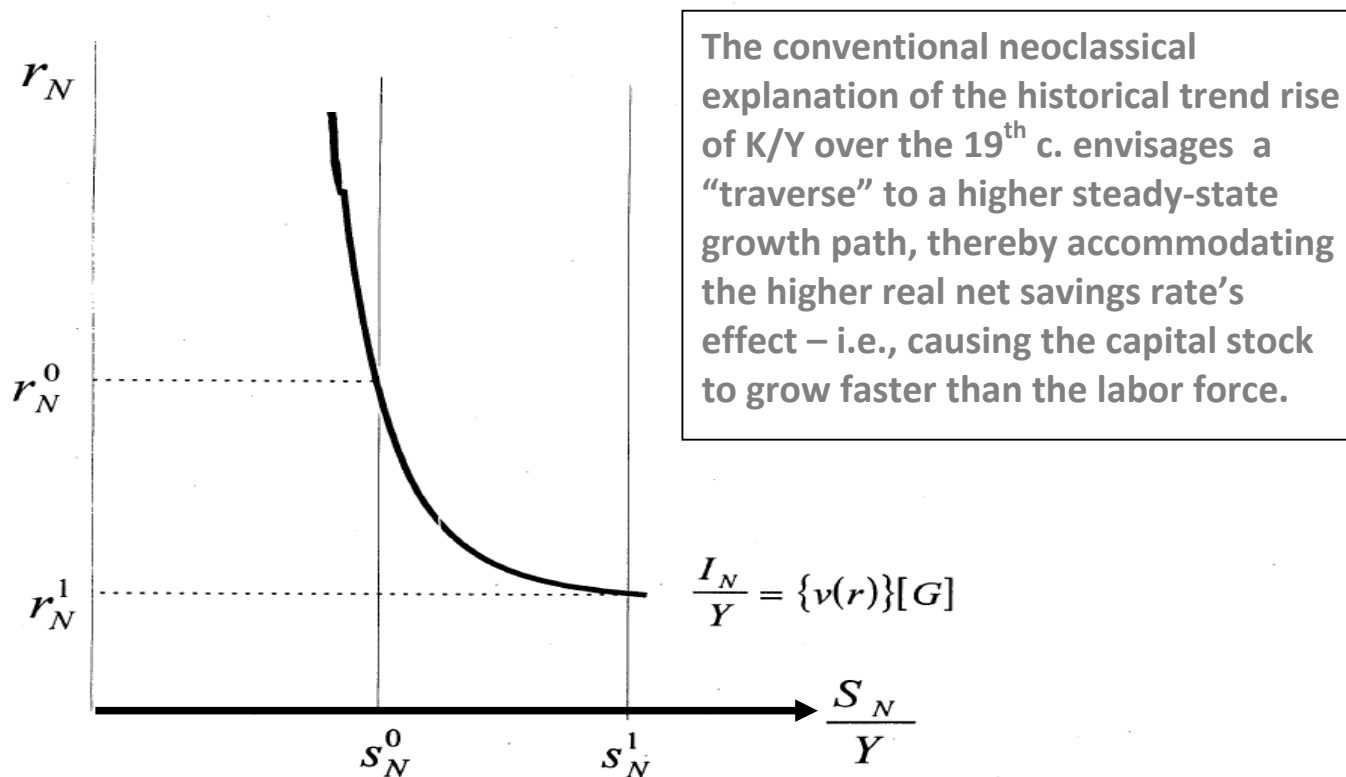


FIGURE 1

An exogenous shift to a higher real net savings rate (in the Solow [1956] growth model) establishes a new equilibrium in the “loanable funds market”, by raising the demand for real net investment relative to real income -- corresponding to the rise induced in the desired $K/Y = v(r)$ when the real net interest rate is forced downwards.

Accounting for the U.S. 'Grand Traverse of the 19th century': Does the Solovian Model Fit?

The Grand Traverse: The U.S. Domestic Economy, c. 1817 to c. 1897

Variables	Average Values for quasi-steady-state periods	
	1800 - 1835	1890 - 1905
$E_L^* = E^*/\theta_L$, labor efficiency g.r.	.0085	.0155
L^* , labor input (manhours) g.r.	.0342	.0243
θ_L , non-property share in gross product	.68	.54
θ_R , unimproved land share in gross product	.09	.09
R^* , unimproved land input g.r.	.0281	.0195
$G = [\theta_L \{L^* + E_L^*\} + \theta_R R^*] / (\theta_L + \theta_R)$, the "natural" rate of growth of output	.0410	.0369
Y^* , the actual rate of growth of output	.0421	.0378
s_G , the real gross savings rate	.11	.28
δ , depreciation rate on reproducible stock	.017	.036
$Bv = s_G / (G + \delta)$, real reproducible capital- output ratio required for steady-state growth	1.90	3.84
v , the actual real capital-output ratio ¹	1.80	3.62
(v/Bv) , actual as fraction of equilibrium capital-output ratio	0.95	0.94

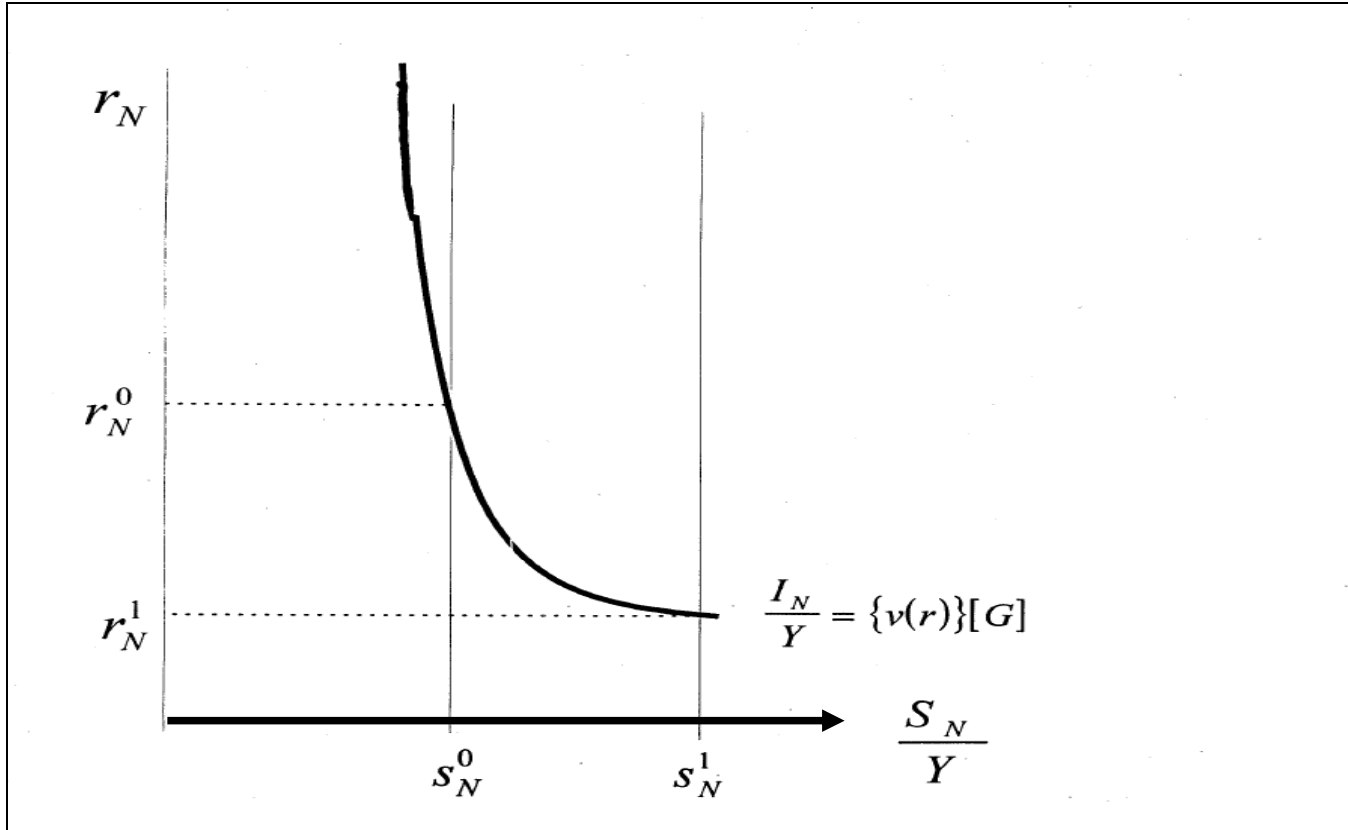
**Dynamics of the U.S. "Grand Traverse" 1835 - 1890:
Adjustment Speed in the Standard NeoClassical Growth Model
(Calculations Assuming Discontinuous Savings Rate Shifts in 1835 and 1871)**

Adjustment Duration Equation (after K. Sato, 1966):

$$t(\varepsilon) = 1/\lambda [\ln\{1 + (\varepsilon/1 - \varepsilon)\}][v(0) / {}_Bv(t)], \text{ where } \varepsilon \text{ is the completion fraction.}$$

Subperiods of "Traverse":	1835-1871	1871-1890
Actual Duration, t (years)	35	19
Estimated Average Adjustment Rate, λ	0.0420	0.0402
Proportional Savings Supply Shift, $s_G(t) / s_G(0)$	(.20/.11)=1.818	(.28/.20)=1.4
Proportional Capital-Output Ratio Adjustment Required,		
${}_Bv(t) / v(0)$	(3.47/1.80) = 1.84	(3.84/3.12)=1.23
Subperiod Endpoint Magnitudes		
	1871	1890
Adjustment Ratio: $(\varepsilon / 1 - \varepsilon) = [\exp\{\lambda t\} - 1][{}_Bv(t) / v(0)]$	6.162	1.410
Implied Fraction of Adjustment Completed, ε	0.86	0.585
Predicted $v(t) = \{[{}_Bv(t) - v(0)] / [v(0)]\varepsilon + 1\}v(0)$	3.10	3.54
Actual $v(t)$	3.12	3.62
Actual Fraction of Full Adjustment Completed,		
$\varepsilon = [v(t)] / [{}_Bv(t)]$	0.90	0.94

Everything seems to fit nicely, but not when you look at what happened to the real interest rate during the Traverse: Remember this graph?



WHAT'S WRONG WITH THIS (Figure 1) PICTURE?

From the vantage-point of the conventional Solow growth model story, nothing is wrong – it's the picture of how a “traverse” to a higher capital-output ratio at full employment would look in the market for loanable funds, i.e., where ex ante savings and investment flows are equilibrated.

The low elasticity of substitution in the production function implies an inelastic investment demand schedule, so that with a savings schedule is of the conventional (Keynesian) interest inelastic form, the shift in the savings rate --which would be required to drive the capital-deepening traverse -- would be expected to substantially depress the real rate of return, as the Figure shows.

But, in the historical actuality of the 19th century U.S. economy, the real net rate of interest only fell moderately, and the real gross rental rate fell even less markedly (from c. 12% to c. 10%). So, somehow the investment demand schedule must have been shifted outwards, and/or the savings supply schedule must have been more interest elastic.

Conclusion: we need another picture, and a correspondingly different story.

TOWARD A BETTER (MORE COMPLICATED) STORY

Non-Harrod-neutral technological change (the capital-deepening kind) would shift the investment demand schedule in the fashion required. How could we know whether there was a capital-deepening bias in 'invention'?

We could look at the relationship between changes in the capital output ratio and the share of capital. If the elasticity of substitution was less than unity, we would expect that if capital input services stock grew faster than output, the share of labor in output would tend to rise and (in a two factor model) the share of capital would shrink.

But if the opposite were observed – and it is observed in the period from c. 1830 to 1890 -- that would imply that others things remaining unchanged, the bias of factor-augmenting technical progress was such that labor inputs measured in efficiency units was tending to grow faster than capital inputs measured in efficiency units. This is what is meant by a (*Harrod*) *capital-deepening bias*: given the real rate of return, the desired ratio of capital (in natural, i.e., physical) unit to output, would be raised by the effect of technological change.

But, to take a second step, further away from the conventional neo-classical story, suppose that the supply of savings was affected by changes in the functional distribution of income. Then the bias of technological change could also change relative factor-input prices and thereby drive an accommodating adjustment in the interest-elastic savings supply schedule.

We might then consider a Pasinetti-type savings function, where the workers consume their earnings and the owners of capital do all the savings, and add the condition that real wage rates are pegged by an elastic supply of labor – not from a Marxian “reserve industrial army of the unemployed,” but by the trans-Atlantic migration of property-less people in response to the existing real earnings differential between America and the European agrarian sector.

4. A better structural model of the Grand Traverse: 'the Cantabridgian Synthesis'

4.1 The parameterized (Cambridge, Mass.-style) model of the real gross investment rate

4.2 The (Cambridge, Eng.-style) model of the real gross savings rate

Specifications for "the Cantabridgian Synthesis"

I. Underlying Structural Equations

(1) Cambridge-Type Nominal Savings Function for Gross Savings in Current Prices

$$\left(\frac{S_G}{Y_T} \right)_t = s_L (\theta_L)_t + s_P (\theta_{TK})_t, \quad \theta_L + \theta_{TK} = 1.$$

(2) Full Employment Condition in Investment Market

$$(S_G / Y_T)_t = [P_k(t)] [I_G / Y]_t$$

(3) Neoclassical Desired Capital-Output Relationship (From CES Production Function)

$$v(t) = Z(t) [E_K(t)]^{-(1-\sigma)} [r_G(t)]^{-\sigma}$$

where

$$v(t) = K(t) / Y(t)$$

$$Z(t) = [1 - \theta_R]^\sigma [E_R(t) \cdot R_t / Y_t]^{-(1-\sigma)\theta_R(1-\theta_R)}$$

(4) Accelerator Type Investment Demand Model (Jorgenson-Type Replacement Demand)

$$(I_G / Y)_t = v(t) [Y_t] + v(t) [\delta_t]$$

(5) Steady-State Growth Condition

$$Y_t^* = G_t$$

Specifying a Pasinetti-type savings function and the investment demand equation:

Savings and Investment Flow Equations:

(6) Planned Rate of Real Gross Savings

$$s_G(t) = [P_k(t)]^{-1} \{ [(s_p - s_L)\theta_R + s_L] + (s_p - s_L)Z(t)[E_k(k)]^{-(1-\sigma)}[r(t)]^{1-\sigma} \}$$

(7) Planned Rate of Real Gross Investment

$$i_G(t) = I_G(t) / Y(t) = Z(t) [G_t + \delta_k][E_k(t)]^{-(1-\sigma)}[r_t(t)]^{-\sigma}$$

(8) Steady-State Full Employment Equilibrium

$$s_G(t) = i_G(t)$$

II. Model Parameter Estimates

Savings Equation (1), estimated from 1800 - 1900 Decadal Observations:

$$\left(\frac{S_G}{Y_T} \right)_t = -0.1140 + 0.7247 \theta_{TK} , \quad \text{implies } (\hat{S}_p) = 0.6107$$

$$(-.03680) \quad (0.0896) \quad \overline{R^2} = 0.628; \quad (\hat{S}_t) = -.1140$$

Production and Investment Demand Function (Eq. 3) Parameters:

$$\text{From: } (K^* - L^*)_t = \left(\frac{\sigma}{(1-\sigma)} \right) [\theta_L^* - \theta_K^*]_t + \lambda$$

From Regression Estimates from Abramovitz and David (1973), David (1977), based on Decadal Growth Rates for 1800 - 1900:

$$\begin{array}{lll} \text{For } K^* = K^*, & \sigma = .08, & \lambda = .015 \\ \text{For } K^* = K^*_T, & \sigma = .20, & \lambda = .017 \end{array}$$

Implied Rate of Capital-Using Technological Change:

$$\begin{aligned} E_K^* &= (E_L^* - \lambda) = -.0039 \\ E_{KT}^* &= (E_L^* - \lambda) = -.0055. \end{aligned}$$

$$E_{KT}(1897) / E_{KT}(1817) = (\exp[E_{KT}^*(t)]) [1897-1817] = (-.0055)(80) = 0.644.$$

III: Parameter Values in Underlying Structural System that are Subject to Shifts:

	1800 - 1835	1890 - 1905
$p_k(t)$	1.081	0.821
$G_t + \delta_t$	0.0580	0.0729
$E_k(t)$	1.00	0.644
$A(t)$	1.603	1.228

Dated Equations (for $\sigma=.08$):	1800 - 1835	1890 - 1905
(6) $s_G(t) =$	$-0.054 + 1.291(r)^{.92}$;	$-0.061 + 2.896(r)^{.92}$
(7) $i_G(t) =$	$0.093(r)^{-.08}$;	$0.233(r)^{-.08}$

Equilibrium Solutions for Equations (6) and (7) – Approximated:

r_e	.11	.10
$s_G = i_G$.11	.28

Hypothetical Solution for Case of Unshifted s_G Schedule, with Shift in i_G Schedule as Specified:

r_{eh}	.11	.22
$S_{gh} = i_{Gh}$.11	.26
$r_{eh} \rightarrow O_{kh}$.32	.60 implied by (4)

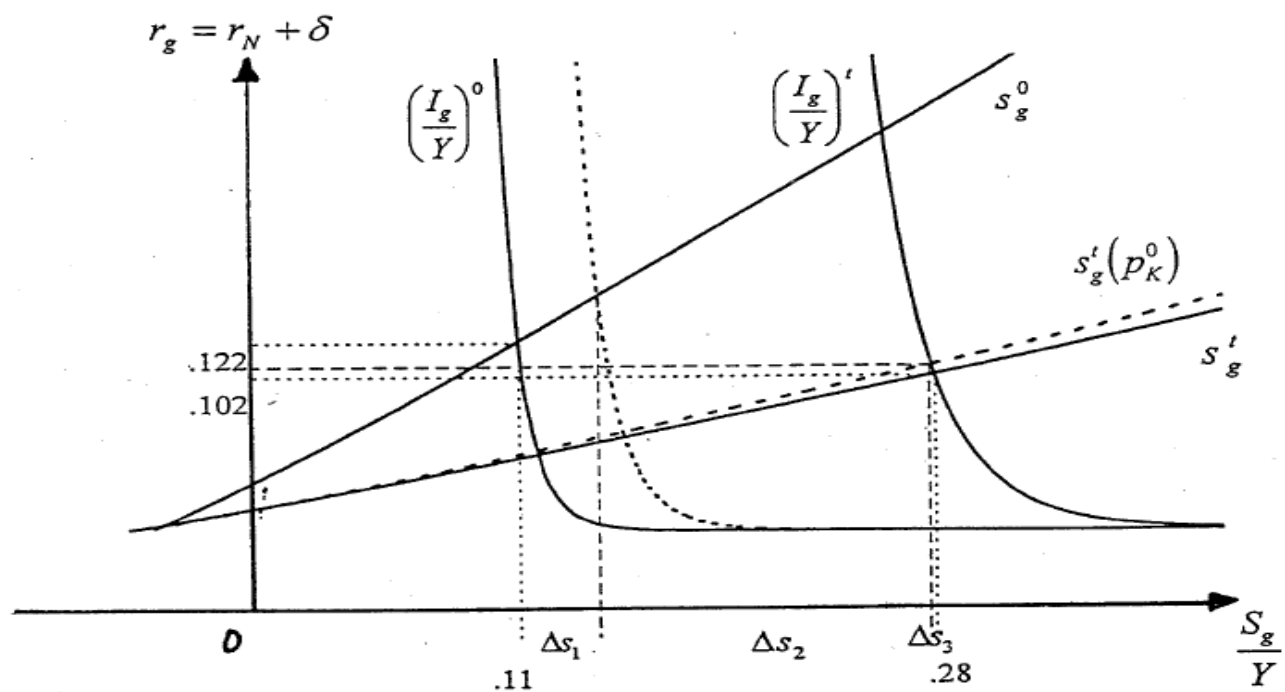


Figure 2: A Cantabridgian Synthesis: Components of the Shift in the U.S. Real Gross Savings Rate between the 1800-35 and 1890-1905 "Golden Ages" (for $\sigma = .08$)

ΔS_1 : Indirect effect of biased technological change upon the depreciation rate, caused by the price-induced expansion or share of investment in shorter-lived capital assets.

ΔS_2 : Direct effect of technological bias towards capital-deepening, i.e., Harrod labour-saving innovations.

ΔS_3 : Indirect effect of biased technological change, in the form of differential productivity growth in producer durables industries leading to relative decline of investment goods prices.

5. Interpretations and Implications

5.1 Contrasting treatment of the savings-rate's rise with alternative stories:

- Kuznets (1955) and Rostow (1960) both argue that rising real income levels translated into higher personal savings rates, and the latter attributes the *supposed* antebellum “take-off” in the 1840’s to the increased pace of capital-formation that this permitted.

Comment: this left the source of the rise in real income to be accounted for, and ignored the importance of foreign lending in relaxing the constraint of domestic savings on domestic capital formation in this period.

- David (1977) proposed that in addition to the elasticity of the availability of loanable funds in the domestic economy due capital imports, demographic change – specifically the decline of fertility in the native-born white population, particularly notable in New England and the Northeast more generally (David and Sanderson 1987) : the shrinkage in the proportion of young dependents released c. 8 percent of GDP that previously had gone into consumption, which almost matched the antebellum rise in real gross private savings. The argument was that the fertility decline stemmed in good part from the diminished demand for child labor on farms in the North (due to mechanization), and the rise of rural non-farm employment opportunities that made it more difficult for heads of farm households to exploit the labor of their young adult children (David and Sundstrom 1988; Carter and Sutch 1992; 2000). The common theme with the current proposition is the endogeneity of the rise in savings that was affected by structural transformations in the economy and society.

5.2 Some implications

In the explanation proposed, the shift in the functional distribution of income and the consequent rise in average savings rate – driven by the capital-deepening bias of innovation – depends in good part upon real wage rates not being pulled up as a consequence of the rapid capital formation. The elasticity of the supply of industrial labor, due to the policy of open immigration that was maintained throughout the traverse era (save for the interruption during the Civil War), then appears a quite crucial.

Recent work (by Ran Abramitzky at Stanford) has shown at the micro-level what aggregate estimates of average non-farm wage earnings intimate: that real wages of immigrants were low and failed to rise significantly until the post WWI era's restrictions on immigration.