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SOURCES OF CONVERGENCE IN THE LATE NINETEENTH CENTURY

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ABSTRACT

Although the empirical growth literature has yielded many findings on postwar convergence patterns, it has had little to say about the determinants of convergence in earlier epochs. This paper investigates convergence for group of seven countries during the period 1870-1914, the last great phase of global convergence before the present postwar era. A standard empirical growth model, the Augmented Solow Model, which includes physical and human capital accumulation, proves unsatisfactory in this setting. Its shortcomings appear to lie in a failure to control for changes in land endowments, a feature of the endogenous frontier dynamics of the period. An alternative neoclassical open-economy factor accumulation model is proposed, which admits capital and labor migration, and may be extended to include a moving frontier. The model explains the observed convergence pattern in the sample, and suggests that factor accumulation patterns were the prime sources of labor productivity convergence from 1870 to 1914. The analysis gives little role to human capital, trade, or technological catch-up as important convergence mechanisms in this group of countries during the era studied. Since factor accumulation was influenced heavily by factor migration in the late nineteenth century, the findings also point to the limited use of conventional closed-economy growth models in this historical setting.

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1. INTRODUCTION

The output of empirical growth research has recently proliferated in the economics literature. This line of work was in part a response to the demand-side challenges of a new growth theory in need of empirical evaluation.[1] It also reflected a supply-side response given the availability of new international comparative data with which to test theories new and old.[2] However, a great many papers have reworked the small and finite set of databases for the contemporary period, a research strategy that faces long-run diminishing returns.

I offer a new and complementary direction for research, one prompted by the historical basis for the convergence debate. I refer here to the notion that convergence dynamics in the global economy warrant scrutiny not just over the last fifty years, but over the last hundred and fifty years or more, a view recently emphasized by Williamson (1996). This long view stood at the center of seminal studies by Abramowitz (1986) and Baumol (1986). Such studies built on the data collecting efforts of Maddison (1982), and these historical papers anticipated the concerns of the recent growth and convergence literature by a number of years. Yet, surprisingly, that new growth literature has devoted little attention to empirical work on periods before 1950 and the dawn of the Summers-Heston data. This is unfortunate for a number of reasons: first, there is certainly historical data there to be analyzed given the effort; second, such data could dramatically increase the sample size for many of the econometric tests of growth theory; third, there is no reason to suppose (and there are good reasons to doubt) that growth and convergence dynamics in the nineteenth and twentieth centuries have followed the same patterns. Present empiricism appears directed at the best fit or the "right" model for a sample of 100 countries for the period 1950–1990. Yet this is not the only interesting empirical exercise conceivable, nor the sole criterion by which to judge theories of economic growth.

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[1] The new growth theory is associated with a large number of authors (Barro 1990; Barro and Sala-i-Martin 1992; Barro, Mankiw and Sala-i-Martin 1992; Lucas 1988; Rebelo 1991; Romer 1986; Romer 1989; Romer 1990; Romer 1993, and others). For a survey see Romer (1994).

[2] The standard postwar data on growth came from the United Nations International Comparisons Project (Heston, et al. 1994; Summers and Heston 1991; Summers, et al. 1993). These same estimates now make their way even into World Bank and IMF publications, and recent compilations by other authors (Barro and Lee 1994) which are in wide use.

This paper makes a new departure, by examining the empirics of growth and convergence in the late nineteenth century for a panel sample of countries at the heart of the emerging "Greater Atlantic" economy of that era. I do not use any postwar data, or out-of-sample projections therefrom, but rather construct a panel of 7 countries from 1870 to 1914. The convergence patterns are laid out in Table 1 and Figures 1–2. I examine both (unconditional) β-convergence (tendency of poor countries to grow faster in a cross-section bivariate regression of growth rates on initial income level), and σ-convergence (tendency of sample dispersion of incomes to diminish). By both criteria, this was an era of convergence, with a convergence speed of about 1% per annum. This is the slope in the regressions and shown in Figure 1 and Table 1. This is also approximately half the rate of decline of the variance of the log of output per worker shown in Figure 2, which falls by about 50% from close to 0.22 in 1870 to about 0.11 in 1914, a rate of decline of 1.8% per annum.[3] The question to be asked is whether these convergence patterns are explicable in terms of any particular growth model.

I begin in Section 2 by applying one of the more robust postwar growth models, the Mankiw-Romer-Weil (Augmented Solow) model. Its performance is disappointing for my sample during the period 1870 to 1914. One should not be surprised by this result, since the basic MRW model (like most other "contemporary" growth models) does not incorporate some key features of the late-nineteenth century economy: it is a closed model, but most economies were open in both goods and factor markets; and,

[3] The concepts of β-convergence and σ-convergence are obviously related, and the link between their convergence properties depends on the nature of the residual variance in the β-convergence regression (Barro and Sala-i-Martin 1992). For example, if the growth dynamics are given by a simple neoclassical model (Barro and Sala-i-Martin 1995, 383–87), then we may write

$$\ln (y_{it}/y_{i,t-1}) = a - (1-e^{-\beta}) \ln (y_{i,t-1}) + u_{it}.$$

If $\beta > 0$ then poor countries grow faster than rich ones in the β-convergence sense. If the disturbances u_{it} are distributed with mean 0 and variance σ^2_u independently of $\ln (y_{i,t-1})$ and u_{jt} (for $j \neq i$) then $\sigma^2{}_t$, the cross-section variance of $\ln(y_{it})$, follows a difference equation,

$$\sigma^2_t = e^{-2\beta}\, \sigma^2_{t-1} + \sigma^2_u,$$

with solution

$$\sigma^2_t = \frac{\sigma^2_u}{1 - e^{-2\beta}} + \left(\sigma^2_0 + \frac{\sigma^2_u}{1 - e^{-2\beta}}\right) e^{-2\beta t}.$$

Thus, β-convergence is a necessary but not sufficient condition for σ-convergence. In the cases where σ-convergence obtains ($\sigma^2_0 > \sigma^2_u/[1 - e^{-2\beta}]$), it can be seen by the above that the rate of decline of σ^2_t is given by $0 < -\text{dln}\,(\sigma^2_t)/dt \le 2\beta$, with the rate equal to 2β in the deterministic case ($\sigma^2_u = 0$).

most critically, it is a model which ignores a key input—it includes labor and capital, but omits land. Land abundance was the very basis for expansion and specialization in the primary-product based frontier economies of the New World. By symmetry, land scarcity was an equally important constraint to growth and structural change in the countries of the Old World.

In Section 3 I review a new model of convergence in a world of open economies with endogenous supplies of land, labor, and capital. Section 4 evaluates this model and discovers that in terms of statistical significance (fit) and quantitative significance (predicting the actual convergence pattern), the new model is quite successful. Although simply based on labor, capital, and land accumulation, the new model is robust to various plausible changes in specification. I can add terms which capture technological catching up, or human capital effects, or trade effects on growth and convergence, and none seem to matter in a statistically or quantitatively significant way.

I conclude that we may need alternative models of economic growth for the late nineteenth century, the last era of global convergence before the postwar period. The important element in such a model should be factor accumulation, which explains almost all of the convergence pattern from 1870 to 1914. The role of other forces such as catching up, human capital or trade appears to be second order.

2. THE AUGMENTED SOLOW MODEL; OR, 1990S GROWTH THEORY MEETS 1890S HISTORY

Is a new growth model needed for the late nineteenth century? To answer this question we might begin by exploiting existing growth models which have been proven in postwar analysis. The simplest place to begin is with the traditional "old" growth theory originating with Solow (1956), and reformulated by Mankiw, Romer, and Weil (1992) (henceforth MRW). The latter paper presents an augmented closed-economy model where growth of output (Y) is driven by the accumulation of physical and human capital (K, H), each with an exogenous savings parameter s_i (i= k, h), and by labor augmenting technological change (A) growing at a constant rate (g). The workforce (L) grows at an exogenous rate (n) and all capital depreciates at an exogenous rate (δ). The model proves remarkably successful in explaining the cross-country variation in growth rates in a postwar sample of countries, and the authors suggest that we think of growth as essentially a neoclassical Solovian process with factor shares of one third for K, H, and L. Forcefully restated by Mankiw (1995), the model can be interpreted as casting doubt on the need for "new" endogenous growth theories as an explanation of variations in patterns of development. Rather, attention might be better focused on the determinants of country-specific accumulation parameters.

I will briefly restate the MRW Augmented Solow Model. The production function is a simple Cobb-Douglas aggregation with constant returns to scale.

$$Y(t) = F(K(t), H(t), A(t)\,L(t)) = K(t)^{\alpha}\, H(t)^{\beta}\, [A(t)\,L(t)]^{1-\alpha-\beta},$$

Define $x(t) = X(t)/L(t)$ as the units of X per worker, and $x^*(t) = X(t)/[A(t)\,L(t)]$ as the units of X per effective worker. Accumulation arises because shares s_k and s_h of output are reinvested in K and H, and units of output are costlessly transformed into either type of capital. Adjusting for labor force growth and depreciation yields formulae for accumulation per effective worker:

$$dk^*/dt = s_k\, y^* - \delta(n+g+\delta)k^*, \qquad dh^*/dt = s_h\, y^* - \delta(n+g+\delta)h^*,$$

Steady state output per effective worker (y^*_{ss}) obtains when factor accumulation per effective worker is zero, $dk^*/dt = dh^*/dt = 0$, which entails that

$$s_k\, y^* = (n+g+\delta)k^*, \qquad s_h\, y^* = (n+g+\delta)h^*, \qquad y^* = k^{*\alpha}\, h^{*\beta}.$$

This set of three equations can be solved for the steady-state values of y^*, k^*, and h^* which I denote y^*_{ss}, k^*_{ss}, and h^*_{ss}. The solution for y^*_{ss} is

$$\ln y^*_{ss} = \frac{\alpha}{1-\alpha-\beta} \ln s_k + \frac{\beta}{1-\alpha-\beta} \ln s_h - \frac{\alpha+\beta}{1-\alpha-\beta} \ln (n+g+\delta)$$

Local convergence to steady state will be governed by a linear dynamical system. Let the speed of convergence for y^* be denoted λ. Using linear approximations one can obtain the following expression for country i, where all countries share a common technology ($A_i = A$, $g_i = g$, $\delta_i = \delta$, for all i), but where parameters s_{ki}, s_{hi}, and n_i vary by country:

$$\frac{1}{T}[\ln y_i^*(T) - \ln y_i^*(0)] = g + \left(\frac{1-e^{-\lambda t}}{T}\right) \ln A(0)$$

$$+ \left(\frac{1-e^{-\lambda t}}{T}\right) \left\{ \frac{\alpha}{1-\alpha-\beta} \ln s_{ki} + \frac{\beta}{1-\alpha-\beta} \ln s_{hi} - \frac{\alpha+\beta}{1-\alpha-\beta} \ln (n_i+g+\delta) \right\} - \left(\frac{1-e^{-\lambda t}}{T}\right) \ln y_i(0)$$

This formula is the basic conditional convergence regression used by MRW. The left-hand side is the growth rate of output per worker. The constant terms on the right-hand side reflect the common production technology, and the next two terms measure the impetus to growth through factor convergence—the more distant an economy is from the equilibrium level of y*, the faster it grows. The equilibrium level of ln y* is given by the term in braces, and its initial level is ln y(0), the final term, which enters with a negative coefficient. This, the so-called "catch-up" term arises not via technology transfer as in other models (e.g., Dowrick and Nguyen (1989)), but as a consequence of pure factor convergence in a model with universal common technologies.

As noted, the model performs well when applied to postwar data. Can it explain the patterns of growth in our panel data set of countries drawn from the late nineteenth century convergence club, the "Greater Atlantic Economy"? Table 2 suggests not. Regressions 4 and 5 apply the model using OLS and AR1 specifications.[4] In Regression 4, the DW statistic is a little low, and in regression 5 the estimate of ρ is significant, so the AR1 correction may matter here. However, the fit of the model is not appreciably improved by using AR1. In neither specification do the accumulation parameters appear significant. In the OLS specification the human capital accumulation parameter has the incorrect sign. In neither specification is the catch up term significant, suggesting that conditional β-convergence in the late nineteenth century is not supported by this model—a finding which clashes with the unconditional convergence results of Table 1. Even if estimated imprecisely, quantitatively the convergence speed is low, 0.4%–0.6% per annum, as compared with the contemporary benchmark of 2% per annum. Finally, in the slightly preferred AR1 specification, the only significant explanator of the current-period growth rate is the last-period growth rate. The persistence is low (ρ=0.386), and this result emphasizes how poorly the model performs: volatile as growth rates are, relying on their persistence is a better guide to growth performance than *any* of the highly persistent accumulation

[4] The AR1 correction was tried as an alternative to counter possible nonspherical disturbances in the form of serial correlation in growth rates at the country level. It is not clear that this should be a serious problem, however, since it is believed that growth rates exhibit less persistence than the usual right-hand side variables in conventional growth models, at least for postwar data (Easterly, et al. 1993). The basic data source is described in the Appendix. The following approximations are made: ln s_k is proxied by ln([dK/dt]/Y); ln s_h is proxied by ln(ENROLL); ln $(n_i+g+\delta)$ is proxied by ln (dlnL/dt + 0.05) following MRW. ENROLL is time-invariant for each country because time series estimates of enrollments are not widely available before 1914.

parameters, an unusual finding which contradicts the conventional view for recent data (Easterly, et al. 1993).

What is wrong with the augmented Solow model in this situation? I will argue that the naïve use of the MRW in the late nineteenth century is inappropriate: first, because the although model is right to focus on pure factor convergence, it focuses on the wrong set of factors; second, because MRW's is a closed-economy model which poorly matches the open-economy conditions prevailing before 1914 in goods and factor markets. The three most important factors in the world economy in the nineteenth century were land, labor, and capital, the three factors at the center of attention in all the work of the classical economists. The MRW model omits land, yet changes in land stocks had profound effects on nineteenth century economic structures, whether it be the expansion of the frontier in the New World, or the decline of agriculture in the Old World. Regressions 6 and 7 suggest why the omission of land accumulation matters. I simply add a variable r^*, the rate of change of land per worker, to the standard MRW regression. It is highly significant and of the correct sign, and it improves the measures of fit markedly.

3. A FACTOR ACCUMULATION THEORY FOR NINETEENTH-CENTURY OPEN ECONOMIES

Obviously, crudely appending land accumulation to the Mankiw–Romer–Weil model is insufficient, and *ad hoc,* and there are other reasons to be dissatisfied with the existing framework. The Solovian model is a closed-economy model, yet we know that much of the factor accumulation of the period was driven by international factor flows. At times Britain was exporting half of domestic savings overseas as foreign investment (Edelstein 1982), and large shares of investment in the New World were driven by the arrival of such capital from Britain and elsewhere, especially in Argentina, Canada, and Australia (Taylor 1992). Similarly, labor, the other mobile factor, was relocating from low-wage Europe to the labor-scarce frontiers (Williamson 1995). Labor flows were also massive, accounting for as much as half of population growth in countries like Argentina, and making nontrivial contributions in North America and Australasia. In itself, the labor migration was a strong pro-convergence force, as real wage gaps narrowed in response to the factor reallocation, but this was offset in part by the capital flows to the rich New World regions, which raised labor scarcity and promoted divergence (Taylor and Williamson 1997).

Thus, both labor and capital were dual scarce factors in the nineteenth century New World regions, relative to abundant land and resources. Capital and labor chased land, and each other, driving a three-factor accumulation dynamic. Even land itself, though not mobile as such, was not a pure fixed factor: capital and labor flows to the frontier raised land scarcity, and this prompted a search for new frontiers and a means to expand the resource base yet further, stimulating a territorial and economic expansion of the global economy through the occupation of new regions and their incorporation into production.

This tale of factor accumulation tells a very different story about growth and convergence than the simple closed-economy Solow model and its variants, and deserves its own investigation. Elsewhere I have constructed an open-economy model of factor accumulation, international factor mobility, growth, and convergence (Taylor 1996), and in the next sections I briefly review this model, and then reconsider the empirics of late nineteenth century growth.

3.1. A general model

In the model, production takes place in a small open economy. Domestic factor endowments are initially fixed, but may be augmented or diminished by international factor flows. Domestic factor accumulation is not considered, but could be added in principle.

The value of output of each final good i (i=1,...,n) depends on prices p_i, a conventional constant-returns-to-scale (CRS) production function F_i, and sectoral use of mobile factors v_{ij} (j=1,...,M) and fixed factors v^F_{ij} (j=1,...,P):

$$x_i = p_i \, F_i(v_{ij}, v^F_{ij}).$$

Many properties of this system are summarized in the revenue function, $\mathfrak{R}(p, v)$ where $p = (p_i)$ is the output price vector, and $v = (v_i, v^F_i)$ is the input vector (Dixit and Norman 1980, 43). Domestic factor prices are given by

$$w_j = \partial\mathfrak{R}/\partial v_j = w_j(p, v).$$

Moreover, the revenue function $\mathfrak{R}$ is concave in v, so that

$$H_{ij} = \partial^2\mathfrak{R}/\partial v_i \partial v_j = \begin{pmatrix} \partial^2\mathfrak{R}/\partial v_i \partial v_j & \partial^2\mathfrak{R}/\partial v_i \partial v^F_j \\ \partial^2\mathfrak{R}/\partial v^F_i \partial v_j & \partial^2\mathfrak{R}_i/\partial v^F_i \partial v^F_j \end{pmatrix} \text{ is negative semi-definite.}$$

The following condition also holds, $\mathfrak{R}_{vv}v = 0$, so that the Hessian matrix H_{ij} has rank at most equal to M+P–1 and is certainly not negative definite. A common assumption in trade theory, made for the sake of tractability of analysis in comparative statics problems, is that H_{ij} has this maximal rank, a condition requiring a precise form of "sufficient substitutability" in production.[5] I make this assumption, which guarantees that the upper-left block of H_{ij} has the following property,

$A_{ij} = -\partial^2\mathfrak{R}/\partial v_i \partial v_j$ is positive definite and symmetric.

World financial markets are assumed to be governed by a fixed interest rate r. Mobile factors have unit prices on world factor markets, prices w_i in domestic markets, and flows m_i are subject to an increasing and strictly convex cost function $\eta_i(m_i)$, where $\eta_i(0)=0$, $\eta'_i(0)=0$, $\eta'_i>0$, and $\eta''_i>0$. Movement cost is measured in terms of world price units of the factor (said price being unity by assumption) and corresponds to, say, the opportunity costs of removing the factor from productive use elsewhere, transporting it and putting it into use at the new location.[6]

Let $b_i(t)$ denote the rational-expectations marginal benefit of an incremental inflow of factor i at an arbitrary time t. Without loss of generality, we normalize world factor prices to be unity for every mobile factor. Working in a continuous time framework, $b_i(t)$ is given by the present value of the difference between national and world factor rewards:

$$b_i(t) = \int_{s=0}^{\infty} (w_i(s) - 1)\, e^{-rs}\, ds \qquad \text{for } i = 1,\ldots, n.$$

The marginal cost of such an incremental flow is given by,

$$c_i(t) = \eta'_i(m_i(t)).$$

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[5] An example of a production technology which fails to satisfy this condition is, of course, the standard 2×2 Heckscher-Ohlin model within the cone of diversification. In that situation, factor prices are a function of output prices only, and the revenue function is $\mathfrak{R}(p,v) = w_L(p)L + w_K(p)K$, and $w_i = \partial\mathfrak{R}/\partial v_i$ depends only on p, for i = K, L. Thus the matrix A is the zero matrix, of rank zero, less than M+P–1=1. Consequently, the present analysis does not go through with the standard technology of the factor-proportions approach to factor prices convergence. The key problem is the absence of any fixed factor (P=0). This and other cases are discussed in more detail in Taylor (1996).

[6] In the present model we neglect domestic factor accumulation, though in principle it can easily be added (it is like a *shift in the* parameter δ_i); rather, in an open-economy framework, we acknowledge that marginal changes in factor endowments will result from international factor mobility, regardless of domestic additions to factor stocks. For the present, then, we abstractly consider all changes in factor stocks as driven by international factor movements.

In equilibrium, flows will be such that $b_i(t) = c_i(t)$ for all i and t, so that we obtain $m_i = \psi_i(b_i)$, where ψ_i is the inverse of η'_i. We may admit a domestic factor depreciation at a rate $\delta_i \geq 0$ for mobile factor i, such that factor accumulation is given by inflows net of depreciation, $dv_i/dt = m_i - \delta_i v_i$. Then we can find the dynamical system governing v_i and b_i,

$$db_i/dt = -[w_i(v(t)) - 1] + rb_i(t), \qquad dv_i/dt = \psi_i(b_i(t)) - \delta_i v_i(t), \quad \text{for all } i,$$

where (by the properties of η) $\psi_i(0)=0$, and $\psi_i'>0$.

An equilibrium (b_i^*, v_i^*) of the dynamical system (3.8) must satisfy

$$\psi(b_i^*) - \delta_i = 0, \qquad w_i(v^*) - 1 = rb_i^*, \qquad \text{for all } i.$$

We will assume that such an equilibrium exists, and, if this is the case, it can be shown that it is unique by the monotonicity and convexity properties of $\mathfrak{R}$ and η. In a neighborhood of the equilibrium (b_i^*, v_i^*) we may linearize the dynamical system, using $(\mathbf{b}', \mathbf{v}')$ as local coordinates in the neighborhood of $(\mathbf{b}^*, \mathbf{v}^*)$, to obtain:

$$\begin{pmatrix} d\mathbf{b}'/dt \\ d\mathbf{v}'/dt \end{pmatrix} = \begin{pmatrix} r\mathbf{I} & \mathbf{A} \\ \mathbf{J} & -\mathbf{D} \end{pmatrix} \begin{pmatrix} \mathbf{b}' \\ \mathbf{v}' \end{pmatrix}$$

where $\mathbf{I}$ = the identity matrix,

$\mathbf{A} = (A_{ij})$, positive definite and symmetric, by the properties of A_{ij},

$\mathbf{J} = \text{diag}(\psi_i'(b_i^*))$, positive definite and symmetric, by the properties of ψ_i,

$\mathbf{D} = \text{diag}(\delta_i)$, positive semi-definite and symmetric, since $\delta_i \geq 0$.

The local dynamics of the system depend on the roots of the characteristic equation,
$\det((\lambda - r)(\lambda\mathbf{I} - r\mathbf{D}) - \mathbf{JA}) = 0$. As is customary, attention is focused on the rational-expectations solutions which lie in the stable set, a stable manifold in $\mathbf{R}^{2n}$, and the dynamics on the stable set are locally determined by the n negative eigenvalues $\lambda_i = \lambda_i(\mathbf{J},\mathbf{D},\mathbf{A},r)$, which are commonly called the *speeds of adjustment* of the system in its normal form.[7]

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[7] In the present application, for the case when $\mathbf{D} = 0$, the speeds of adjustment of the system satisfy $\lambda(\lambda - r) = \mu \in \text{eig}\,\mathbf{JA}$. Each $|\lambda|$ is an increasing function of μ, which is an increasing function of each J_i. This last result is particularly intuitive: when transport costs (in the form of the adjustment cost function η_i) undergo positive productivity shocks (the η_i function has a multiplicative shift down), then $\psi_i = \eta'^{-1}_i$ increases, as does $J_i = \psi'_i$; thus increased factor mobility, in the form of declining transport costs, increases the speed of adjustment in the neighborhood of equilibrium.

3.2. A simple model: a one-sector, four-factor world

Consider the special case of a small open economy with a one-sector, four-factor, constant-returns-to-scale (CRS) aggregate production function of Cobb-Douglas form $X=L^{\alpha}K^{\beta}R^{\gamma}F^{\theta}$, where X is output, L is labor endowment, K is capital endowment, R is potentially mobile resource input (say, minerals), and F is a fixed resource input (say, land). CRS implies that $\alpha + \beta + \gamma + \theta = 1$. Suppose that only L, K are internationally mobile, and factor durability is characterized by $\delta_L = \delta_K = 0$. We may now see how the mechanics of the model work and an illustrative example is provided by the case of two-factor (capital and labor) mobility. Here the linearized system takes the following form, with the ψ' evaluated at the equilibrium:

$$(3.11)\quad \frac{d}{dt}\begin{pmatrix} b_L \\ b_K \\ L \\ K \end{pmatrix} = \begin{pmatrix} r & 0 & A_{LL} & A_{LK} \\ 0 & r & A_{KL} & A_{KK} \\ \psi'_L & 0 & 0 & 0 \\ 0 & \psi'_K & 0 & 0 \end{pmatrix}\begin{pmatrix} b_L \\ b_K \\ L \\ K \end{pmatrix}.$$

From the production function we can see that factor prices in the basic model are always given by

$$\begin{aligned}(3.12)\quad w_L &= \alpha L^{\alpha-1}K^{\beta}R^{\gamma}F^{\theta} = \alpha(X/L);\\ w_K &= \beta L^{\alpha}K^{\beta-1}R^{\gamma}F^{\theta} = \beta(X/K);\\ w_R &= \gamma L^{\alpha}K^{\beta}R^{\gamma-1}F^{\theta} = \gamma(X/R);\\ w_F &= \theta L^{\alpha}K^{\beta}R^{\gamma}F^{\theta-1} = \theta(X/F).\end{aligned}$$

Note that wage and output per worker convergence are identical in the basic model. We may plot iso-w_L and iso-w_K contours in the phase diagram to illustrate the convergence properties of the transitional dynamics, as in Figure 3. Here, an equilibrium at V^1 is shown, with initial factor endowment given by V^0. Initially the economy is labor scarce ($w_L>1$) and capital scarce ($w_K>1$) relative to the world. Various possible transitional dynamics are illustrated. Trajectory A corresponds to a case with quasi-mobile labor and capital. Case B is a trajectory with higher labor adjustment costs (ψ'_L) than A and case C a trajectory with higher capital adjustment costs (ψ'_K) than A. Case D is immobile labor, and case E is immobile capital, and in D and E the steady states are at the end of these trajectories on the lines $w_K=1$ and $w_K=1$ respectively.

A basic finding is that the presence of factor mobility may generate convergence *or* divergence: in Figure 3, along certain trajectories, we temporarily (B), and sometimes perpetually (A), move in the direction of increasing w_L (or X/L) from a relatively high initial level of w_L (or X/L). Thus, in general, the introduction of factor mobility may introduce permanent or transitory divergence, and may (or may not) lead to long-run convergence. This important divergence result shows that the predictions of the standard two-factor neoclassical growth model, where factor mobility *always* promotes convergence, do not generalize to the many-factor case (Barro, Mankiw and Sala-i-Martin 1992). Here, convergence properties are more ambiguous. They depend critically on which factors are mobile and how mobile they are (adjustment costs in the dynamic specification); and they also depend on the prevailing relative factor scarcities (initial conditions imply that the convergence property exhibits path dependence). With no clear predictions offered by theory, the nature of convergence is inherently an empirical question.

Finally, we may note a simple extension. Although land is initially considered fixed in this model, it could be easily introduced as a "mobile resource" R. Redefining R as land, and treating F as other fixed factors, we may derive a version of the model to include an endogenous frontier with a variant of the frontier dynamics suggested by Findlay (1995). Let the country be a New World region, like the United States, with domestic capital and labor stocks K and L, and current territorial land R, which has a price w_R. Beyond the frontier, usable land is available at a very low opportunity cost $\phi \geq 0$, which is close to or equal to zero. These costs include the amortized fixed and variable costs of military occupation (armies to fight indigenous peoples), policing the acquired land (forts, sheriffs, etc.), and alienation of the land by the state. Beyond that, possession of the land for profitable use in the private economy requires only its "migration" into the aggregate factor endowment of the country. This may occur in practice as the moving of wagons to locales like Oklahoma and folks rushing off to stake a claim. In theory, we can abstractly model this phenomenon by having the land "migrate": consider the putative trans-frontier land as being in another country at a price ϕ and available for movement into production in the domestic economy via a transaction cost function η_R of the usual kind. With the frontier simply redrawn on the map as this "migration" of land occurs, this scenario now fits exactly the terms of the present model. The frontier moves so long as $w_R > \phi$, which might be always true, in which case expansion proceeds until all land is absorbed, with $R = R_{max}$, and the frontier is closed.[8]

In yet more detail, one could easily posit a position-varying land opportunity cost $\phi(R)$, where land is initially easy to come by, but costs could rise along a Ricardian-style gradient as we approach natural economic constraints (mountains on the edge of prairie; indigenous peoples putting up fiercer resistance; or land quality subject to deterioration) or along the radial dimension in a concentric von Thunen model.[9] This leads to a more refined economic geography. With such a variable ϕ depending on R, the endowments of land, capital, and labor may initially be in equilibrium with no frontier expansion pressure ($w_R = \phi$). Such a situation may describe the United States before the breaching of the Appalachian barrier.[10] Subsequently, various shocks might upset this equilibrium and prompt movement: labor or capital accumulation (from saving, population growth, or factor migration due to lowered international transportation costs) would increase land scarcity, raising w_R; similarly, exploration of the interior may reduce the uncertainty and technology (military, infrastructure, communications, internal transportation) the costs ϕ of expanding west. In this manner, exactly the kind of frontier dynamics envisaged by Findlay can be incorporated into the present model.[11] The reverse dynamics apply in the Old World, where a retreat along the Ricardian frontier might ensue if the "safety valve" of European emigration encourages labor and capital to leave, and marginal lands are retired when $w_R < \phi(R)$. The overall structure, given present knowledge of factor accumulation in the late nineteenth centuries for our sample countries, suggests we use

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[8] Of course, this device invites an application of the model, self-referentially, to the process of inter-regional migration of resources and regional convergence, a subject now deservedly reattracting attention (Slaughter 1995; Kim 1995); we could equally well impose labor and capital migration models for the United States regions, and treat land as "non-migratory" and fixed at the regional level.

[9] Cronon (1991) represents an application of this idea in thinking about the development of Chicago and the Great West in the nineteenth century.

[10] Of course, at this earlier juncture the relevant geographical scale was of smaller dimension, and the model might be applied to the Eastern lands themselves, with their own gradients from cities, to hinterlands, to foothills.

[11] There is one major difference between this model and the Findlay (1995) model. Findlay considers the stock of land as subject to convex use costs. Here, I consider the flow of land subject to convex accumulation costs. If my $\phi(R)$ is convex, then the static equilibrium of the present model resembles the Findlay model in its determination of the frontier location. The generalization here is that I have chosen to make land flows subject to adjustment costs in order to make the treatment of this factor the same as the treatment of labor and capital.

a general model with three-factor accumulation covering labor (L), capital (K), and land (R)—the key inputs favored by the classical economists writing in the same era.

4. EMPIRICS: THE THREE-FACTOR ACCUMULATION MODEL

In this section, I evaluate the performance of a basic empirical growth model based on the factor accumulation approach of the previous section. For example, consider a general aggregate production function of the form $Y = A\,F(v)$, where F has constant returns to scale, and A is a TFP shift parameter. Under competitive conditions, factor prices equal marginal product, and log differentiating the production function yields the formula for the growth rate:

$$d\,\ln(Y/L)/dt = d\,\ln A/dt + \Sigma_j\, \alpha_j\, d\,\ln(v_j/L)/dt$$

Suppose v is converging to a steady state v_{ss}, with local dynamics

$$d\,\ln(v_j/L)/dt = \Sigma_k\, M_{jk}\,\{\ln(v_k/L) - \ln(v_{ssk}/L)\}$$

Suppose technology transfer takes place and A in each country is converging to world best practice A_{bp} with dynamics

$$d\,\ln A/dt = g + \mu\,(\ln A_{bp} - \ln A)$$

Then the growth rate of output is given by

$$d\,\ln(Y/L)/dt = g + \mu\,(\ln A_{bp} - \ln A) + \Sigma_{jk}\alpha_j\, M_{jk}\,\{\ln(v_k/L) - \ln(v_{ssk}/L)\}$$

Which we can write as

$$d\,\ln(Y/L)/dt = g + \mu\,\ln A_{bp} + \Sigma_j\, \alpha_j\, d\,\ln(v_j/L)/dt - \mu\,\ln A$$

Thus, if we consider land, labor and capital as inputs, and if there is no technology transfer ($\mu=0$), and if we admit the possibility that countries i have different rates of technical change that are exogenous ($g=g_i$ in country i), then this equation becomes:

$$d\,\ln(Y/L)/dt = g_i + \alpha_K\, d\,\ln(K/L)/dt + \alpha_R\, d\,\ln(R/L)/dt$$

I term this the basic model. A common intercept ($g_i=g$ for all i) would be an additional possible restriction on the basic model, corresponding to uniform underlying growth rates (or weak convergence, as opposed to strong convergence in levels). An alternative approach, which I term the extended model, might admit catching up via technology transfer (strong convergence), and could include human capital as an additional accumulable factor, following the new growth theory and the neo-Solovian MRW model discussed above:

$$d\,\ln(Y/L)/dt = [g + \mu\,\ln A_{bp}] + \alpha_K\, d\,\ln(K/L)/dt + \alpha_R\, d\,\ln(R/L)/dt + \alpha_H\, d\,\ln(H/L)/dt - \mu\,\ln A$$

Note that, under some very simple factor accumulation dynamics, separable in each factor, when $M = -\lambda I$, each factor endowment converges to steady state at with a convergence speed λ, according to $d \ln(v_j/L)/dt = -\lambda \{\ln(v_k/L) - \ln(v_{ssk}/L)\}$, and the last equation may be rewritten a couple of ways:

$$
\begin{aligned}
d \ln(Y/L)/dt = g \\
&+ \lambda [\alpha_K \ln(K/L)_{ss} + \alpha_R \ln(R/L)_{ss} + \alpha_H \ln(H/L)_{ss}] \\
&- \lambda [\alpha_K \ln(K/L) + \alpha_R \ln(R/L) + \alpha_H \ln(H/L)] + \mu \ln A_{bp} - \mu \ln A
\end{aligned}
$$

$$
\begin{aligned}
d \ln(Y/L)/dt &= g + \lambda [\ln(Y/L)_{ss} - \ln(Y/L)] + (\mu - \lambda) \ln[A_{bp} - \ln A] \\
&= \{g + \lambda \ln(Y/L)_{ss} + (\mu - \lambda) \ln A_{bp}\} - \lambda \ln(Y/L) - (\mu - \lambda) \ln A
\end{aligned}
$$

This formula implies that overall convergence in output per worker depends on factor convergence at a speed λ and productivity convergence at a speed μ. Thus $\mu=0$ (and we have pure *factor convergence*) if and only if the coefficients on the levels of log output per worker, $\ln(Y/L)$, and log of TFP, $\ln A$, are equal and opposite in the above equation; on the other hand, $\lambda=0$ (and we have pure *productivity convergence*) if and only if the output term has a zero coefficient. More generally, both forces may be at work with both λ and μ nonzero.[12]

However, we should note that the above simplification and comparison with the MRW regression model rests on assumptions that factor accumulation dynamics are separable with $M = -\lambda I$. This is possible when (as in MRW) factor accumulation is given by exogenous parameters in a closed economy. Such is unlikely to be the case in a historical setting with open factor markets and endogenous factor endowments, where factors chasing each other leads to feedback effects (e.g., a labor inflow prompts an incipient capital inflow, or vice versa). These richer dynamics *are* captured in the

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[12] Milbourne (1995) has formally shown that this kind of procedure can be applied to the MRW model to distinguish *factor convergence* from *productivity convergence*, and since this is a useful distinction, we will keep it in mind here. Formally, Milbourne relaxes the assumption that all countries are on the same production function. Instead, technical change g_i in country i is subject to catching according to the gap between actual practice A_i and "best practice" A^*, with $g_i = g + \theta[\ln A^* - \ln A_i(t)]$. Under these conditions, and making approximations for small θ, the MRW regression equation becomes:

$$
(\ln y^*(T) - \ln y^*(0))/T = \text{const.} + \left(\frac{1-e^{-\lambda t}}{T}\right)\left\{\frac{\alpha}{1-\alpha-\beta}\ln s_{ki} + \frac{\beta}{1-\alpha-\beta}\ln s_{hi} - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n_i + g + \delta)\right\}
$$

$$
-\left(\frac{1-e^{-\lambda t}}{T}\right)\ln y_i(0) + \left\{\left(\frac{1-e^{-\lambda t}}{T}\right) + \frac{(\alpha+\beta)\,\theta}{(1-\alpha-\beta)\left(n_i+g+\delta\right)} - \theta\right\}\ln A_i(0)
$$

Here, when $\theta=0$, the coefficients of $\ln y_i(0)$ and $\ln A_i(0)$ are equal and opposite.

dynamics of the new model by the off-diagonal elements in the A matrix (the cross-derivatives of the revenue function reveal the change in, say, the wage in response to an increment in capital).

4.1. The Basic Model

Table 3 applies the basic model to our sample. The model performs respectably well, at least compared to the Augmented Solow Model. In Regressions 8 and 10 the rate of change of output per worker (y*) depends on the rate of change of capital per worker (k*) and land per worker (r*). These coefficients are signed correctly, and mostly significant.[13] Regressions 12 through 15 explore the possibility that the basic model fails to fully explain differences in country growth rate levels by allowing fixed effects (varying country intercepts). The omitted country is Australia, which has the lowest growth rate. Perhaps only the United States (+1.6% per annum) and, at a pinch, Denmark (+1.4%) are significant over-performers by this reckoning using OLS.[14]

These results suggest that the basic model performs well for our panel data sample of "Greater Atlantic" economies from 1870–1914. I will treat Regression 8 as the baseline model, since the other variants add little. The coefficient of k* suggests capital's share is about one half, *if* capital is correctly measured. This is not implausible. It *is* implausible to think that land is correctly measured, since we expect true land stocks to be affected by the land quality gradient within countries, and by geo-climatic differences across countries. For example, if quality differences between marginal measured changes and average levels matter, then we might expect a relationship Δ ln(observed land) = β Δ ln(true land), with $\beta \neq 1$. Thus, if land data is not commensurable, we cannot interpret the coefficient on r* as land's share—which is fortunate, since a share of 0.4 is probably too high.

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[13] An endogeneity correction (Regressions 9 and 11) proves unnecessary, as the specification test prefers the plain OLS and AR1 specifications. Correcting for serial correlation is of debatable importance: the DW statistic in Regression 8 and the estimated ρ in Regression 10 are of borderline significance. I take an agnostic stance and retain both OLS and AR1 estimates throughout for comparison.

[14] Using AR1, the fixed effects hypothesis can be rejected in favor of pooled OLS, although the AR1 correction is not justified with fixed effects present (the DW in 12 is acceptable, and the ρ in 14 is not significant). Again, the endogeneity correction is unnecessary.

4.2. Quantitative Performance: Tracking Convergence

Beyond goodness of fit, and statistical significance of the explanatory variables, how well does this model perform in explaining the observed convergence in our sample from 1870 to 1914? To answer this question I take the fitted values from Regressions 8 as the model's predicted growth rates.

Cumulating from 1870 onwards, we obtain the predicted values of the levels of output per worker given the 1870 distribution. This predicted pattern of output per worker evolution can then be examined to give the predicted σ-convergence path predicted by the model, and this can be compared to the actual path. Figure 2 showed the actual σ-convergence 1870–1914, an approximate halving of the coefficient of variation of output per worker, the bulk of this in the 1890s. Figure 4 shows the basic model's predicted σ-convergence, which closely follows the actual path, regardless of whether OLS or AR1 models are employed. I conclude that besides good statistical fit, the model's accurate tracking of the observed trends in σ-convergence enhances its credibility.

Is the basic model a sufficient explanation of the pattern of growth and convergence 1870–1914 in my sample? Can the omission of catching up via technological change be justified? What about the contribution of human capital accumulation to growth? What about the role of commodity market integration as a source of convergence? To address these objections, I tried to employ the extended model as an alternative, and I also investigated the impact of terms-of-trade changes on growth performance.

4.3. Catching Up; or, Productivity Convergence Versus Factor Convergence

Table 4 investigates the possible role of a so-called "catch-up" term as an additional explanator in the growth equation. Regressions 16 and 17 use the naïve catch-up term commonly seen in the literature, initial level of output per worker. The term is not significant in OLS and AR1 specifications.

However, as the extended model indicates, TFP convergence might be driven by the TFP gap, not the output per worker gap, since some differences in output might be attributable to differing factor endowments and not to technology differences (as in the Solow model). Thus, Regressions 18 and 19 utilize a TFP measure (lna) estimated as the residual from an AR1 regression of the *level* of lny on the *levels* of lnk and lnr.

However, this catch-up term is not significant either, whether we use OLS or AR1. When *both* types of catch-up term are added, in addition to accumulation controls, as in Regressions 20 and 21, neither is significant. But when *only* the catch-up terms are added, as in Regressions 22 and 23, predictable results follow: first, the unconditional convergence results of Table 1 are replicated, and lny(0) has a significant negative coefficient of –0.015; second, lna(0) has an insignificant coefficient different from the coefficient on lny; third, with OLS, the endogeneity correction matters.

I interpret these latter results as follows: unconditional convergence *is* present, and if factor accumulation were of the simple separable form, we could conclude that both factor convergence and productivity convergence were present, since the coefficients on lny and lna differ. However, the endogeneity correction in the reduced form Regression 22 warns that the factor convergence dynamics may be more complicated. Utilizing instead the structural growth regressions (18 & 19) indicates that given observed factor accumulation there is no residual role for TFP catching up. Thus, we are closer to the open economy multi-factor accumulation dynamics of the basic model, than to a simple separable factor accumulation dynamic as in the MRW model. And in the present case, there appears to be no role for technological catch up once we control for factor accumulation.

Beyond making a judgment solely based on a statistical evaluation of the regressions, we can ask how the estimated contribution of TFP catch up matters in predicting σ-convergence. I used Regressions 16 through 19 to generate a growth component due to the "catch-up" term by setting all other right-hand side variables equal to a constant, and generating a fitted value. The results were cumulated from 1870 to generate predicted levels of output per worker, and predicted versus actual dispersion is shown in Figure 5. It is clear that no specification produces a quantitatively significant role for catching up in accounting for the observed pattern of σ-convergence.

4.4. Human Capital

We have now justified the omission of a catching up term from the basic model—but have we controlled for all the relevant forms of factor accumulation? Recent growth empirics, including MRW and other studies in the "new growth" tradition, have found a significant role for human capital as an explanator of growth performance.

I tried augmenting the basic model by adding a variable equal to the log of enrollment of children in schools, the same proxy of human capital accumulation found in MRW, denoted $\ln(s_H)$. The data is not available to produce this variable for every period in every country at the turn of the century, so a time-invariant estimate had to be used, compiled by O'Rourke and Williamson (1995), and largely based on the statistics of Mitchell (1992; 1993).

Table 5 shows the results. Again, the endogeneity correction is unnecessary, and the choice between OLS and AR1 specifications is borderline. Unlike the MRW model (Table 2), the human capital variable has the correct sign in both OLS and AR1 specifications, a reassuring finding. However, it is not significant in either case. Otherwise, the estimated coefficients resemble those of the basic model (Table 3). To examine the quantitative significance of the human capital term I again generated a fitted value growth component equal to the contribution of the human capital term. I then generated a fitted level of y after 1870 by cumulating these growth rates, and I compared the dispersion of these fitted levels with the actual dispersion trends.

Figure 6 shows that human capital accumulation was, if anything, an anti-convergence force during this period for the present sample of countries. This follows from the fact that richer countries like the U.S. and Australia had higher enrollments then poorer countries like Sweden and Denmark, and this, *ceteris paribus*, would have tended to increase the dispersion of output per worker. This finding that human capital might have had a small role in producing convergence before 1914 was identified by O'Rourke and Williamson (1995), and challenges conventional views of Scandinavian catch-up as being a result of human capital-based growth—in contrast to, say, the growth path of Spain and other parts of peripheral Europe. The method invites extension to broader samples, and to time-series or panel tests: at present the variable ENROLL is very crude proxy for human capital (albeit no cruder than some contemporary data), and contains no time-dimension information for each country. For the present, a qualified conclusion would have to state that evidence for human-capital effects in late nineteenth century convergence is quite weak.

4.5. Trade

The basic and extended models have been applied, and the basic model favored. Yet each omits one last avenue of convergence, trade, which has been extensively studied both in the contemporary period (Ben-David 1995; 1993) and in the late nineteenth century (O'Rourke and Williamson 1994; O'Rourke, Taylor and Williamson 1996). The latter studies applied standard trade models to patterns of convergence both of real wages and relative factor prices in the current sample using econometrics, and, for the Anglo-American case, using CGE simulations. A key lesson of these papers was that factor price convergence was indeed driven in part by commodity price (terms-of-trade changes) between manufactures and agricultural products, although factor endowments also mattered.

Could the terms of trade be an omitted variable in the present study? The original findings of Heckscher and Ohlin (Flam and Flanders 1991) did indeed have ramifications for the absolute standard of living, or productivity, as well as for relative factor prices. This view is often characterized as associating the New World grain invasion as producing lower prices for food and higher rewards for the relatively abundant factor (labor) in the Old World, and hence higher real wages in Europe. Could these effects be large, of first order importance, in the present context?

O'Rourke and Williamson (1994; 1995) addressed the absolute real wage effects of terms of trade changes for both the Anglo-American and Scandinavian cases. The results were not very favorable to the hypothesis that trade made a great difference to growth and convergence: for example, in the Scandinavian cases "open economy forces" might have explained 50% of Anglo-Scandinavian convergence, but of that 50% less than 4% could be due to commodity price convergence, a distinctly second order effect; much more was due to capital and labor accumulation patterns. Is the same true for the present sample, and can the effects of trade be estimated econometrically?

Table 6 attempts to do this by adding an additional variable to the basic model, the terms of trade (tot* = dln(PA/PM)/dt, where PA is an agricultural price deflator, PM a manufacturing price deflator). The terms of trade might be expected to have different impacts in the primary exporting New World versus in the primary importing Old World, so dummy interaction terms are also included, NW × tot* and OW × tot*. The bottom line is that the different trends in the terms of trade do not influence growth performance. The tot* variable is never statistically significant. Moreover, Figure 7 shows that the fitted value of the terms-of-trade growth component contributes nothing to observed σ-convergence after 1870 when we again cumulate growth fitted values and compare the dispersion of the actual levels of y with that predicted by the fitted component (I used Regressions 28 & 29).[15]

Once again, the basic model appears to be preferred to an augmented alternative: almost all of actual σ-convergence from 1870 to 1914 can be explained by a simple three-factor accumulation model which incorporates the classical factors of production, land, labor, and capital.

5. CONCLUSIONS

I have argued that convergence in the late nineteenth century could be explained by a growth model, though not one of the standard type. More generally, my findings caution that any growth model must be carefully tailored to the specific historical circumstances in which it is to be applied—the fields of economic growth and economic history thus have always usefully informed each other.

In the present study contemporary closed-economy neoclassical models proved unsatisfactory as tools for understanding growth dynamics in the 1870–1914 period. Instead, I offered a model with open factor markets and frontier dynamics, reflecting the massive migratory flows of labor and capital to the resource-abundant New World in the late nineteenth century. An empirical framework built around the three classical factor inputs yields a statistically significant explanation of growth patterns, and a quantitatively significant prediction of the degree of convergence actually seen. In contrast, the forces of trade, human capital, and technology transfer appeared second order. Overall, the results extend and encourage ongoing historical research into the nature and consequences of globalization and economic convergence as viewed from the perspective of late nineteenth-century international experience.

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[15] There are theoretical grounds for not being surprised by this result. Consider a normal production possibility frontier, and a small change in the terms of trade when close to the integrated equilibrium. Changes in factor prices (both real and relative) will indeed be first order, whether in a Heckscher-Ohlin or Ricardo-Viner model, since the revenue function has a nonzero derivative $\partial^2 R/\partial v_j \partial p_i = \partial w_j/\partial p_i$. However, changes in *real* output per worker should be second order in any model, since the change in output is equal to the counterfactual dead weight loss when factors do not reallocate between sectors—a second order Harberger triangle for small changes in prices.

APPENDIX

The basic data is largely based on the dataset used in O'Rourke, Taylor, and Williamson (1996). The only changes were to make all outputs and inputs commensurate by converting to standard units, and to add an enrollment rate variable, as follows. The dataset is available from the author upon request.

Y was converted to millions of 1900 British pounds; the 1910–14 benchmark was taken from the 1913 benchmark of Maddison (Maddison 1991, 199, Table A3); the UK level adjusted to reflect share of British (36,207; O'Rourke, Taylor, and Williamson data) in total UK population (45,436; Maddison data) ; the 1910-14 British level of Y is from Mitchell (1992).

LAND was converted to thousands of acres. For the USA figures were revised to include grazing areas, using *Historical Statistics* (1960) series E50 (Total land in Farms) and E61 (Grazing Land).

K was converted to millions of 1910–14 British pounds. AUS set using the figure of £1614 million of 1910/11 in 1910–14 (O'Rourke, Taylor, and Williamson data). USA raw figure of $237,752 million of 1929 in 1910–14 corrected using ratio of wholesale price index in 1910 to 1929 (36.4/49.1) to give $176,256 million of 1910 value (*Historical Statistics* cited in Hughes and Cain (1993)) and converted using par exchange rate $4.86=£1 to give £36,266 million of 1910. FRA raw figure of FFr13,2891 million of 1908-12 converted using par exchange rate of FFr25.23=£1 to give £5,267 million of 1908–12; this used as 1910–14 figure. GER raw figure of M243,548 million of 1913 converted using par exchange rate of M20.43=£1 to give £11921 million of 1913.; this used as 1910–14 figure. GBR raw figure of £4,394 million of 1900 used as 1910–14 raw figure. DEN indirect calculation uses capital-output ratio in 1910-14 given in 1929 million Kr as 11,869/3,707 (O'Rourke, Taylor, and Williamson data); this used to scale DEN Y as above; SWE capital-output ratio in 1910-14 given in 1900 to 1913 million Kr as 7,480/3,740 (O'Rourke, Taylor, and Williamson data); this used to scale SWE Y as above.

ENROLL is the O'Rourke-Williamson (1995) enrollment rate, a constant over time for each country. Mostly from Mitchell (1992; 1993).

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Table 1: Beta Convergence, 1870–1914

	(1)	(2)	(3)
Method	OLS	AR1	OLS
Sample	Panel	Panel	Cross-section
NOBS	49	42	7
R squared	.53	.61	.88
R squared adjusted	.05	.19	.38
Mean Dep. Var.	0.014	0.014	0.014
SEE	0.014	0.013	0.006
DW	1.48	2.23	2.46
Constant	-0.009 (0.70)	-0.024 (1.14)	-0.020 (1.25)
y(0)	-0.009 (1.83)	-0.015 (1.87)	-0.012 (2.16)
ρ		0.387 (2.45)	

Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
See text.
Sources:
See appendix.

Table 2: Augmented Solow Model, 1870–1914

	(4)	(5)	(6)	(7)
Method	OLS	AR1	OLS	AR1
Sample	Panel	Panel	Panel	Panel
NOBS	49	42	49	42
R squared	.54	.65	.58	.70
R squared adjusted	.01	.20	.09	.30
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.014	0.013	0.014	0.012
DW	1.43	2.14	1.52	2.29
Constant	-0.073 (1.08)	-0.155 (2.11)	-0.025 (0.36)	-0.016 (0.18)
y(0)	-0.004 (0.59)	-0.006 (0.57)	-0.003 (0.42)	-0.004 (0.41)
ln (sK)	0.004 (0.77)	0.005 (0.89)	0.004 (0.91)	0.004 (0.73)
ln(sH)	-0.001 (0.04)	0.001 (0.05)	-0.001 (0.06)	0.001 (0.05)
ln(n+g+d)	-0.031 (0.99)	-0.061 (1.90)	-0.017 (0.54)	-0.014 (0.40)
*r**			0.408 (2.17)	0.651 (2.55)
ρ		0.386 (2.51)		0.324 (2.24)

Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
See text.
Sources:
See appendix.

Table 3: Factor Accumulation Model, 1870–1914

	(8)	(9)	(10)	(11)
Method	OLS	IV	AR1	AR1-IV
Sample	Panel	Panel	Panel	Panel
NOBS	49	49	42	42
R squared	.63	.60	.71	.58
R squared adjusted	.23	.18	.38	.10
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.013	0.013	0.011	0.014
DW	1.67	1.78	2.21	2.76
Constant	0.014 (4.93)	0.011 (2.58)	0.020 (5.04)	0.028 (1.36)
k^*	0.479 (2.69)	0.789 (2.62)	0.276 (1.50)	0.326 (0.33)
r^*	0.429 (2.88)	0.371 (1.34)	0.651 (3.44)	0.456 (0.98)
ρ			0.290 (2.11)	0.856 (2.95)
Endogeniety test p-value	.62	—	.84	—

	(12)	(13)	(14)	(15)
Method	OLS	IV	AR1	AR1-IV
Sample	Panel	Panel	Panel	Panel
NOBS	49	49	42	42
R squared	.71	.60	.74	.44
R squared adjusted	.31	.06	.34	-.43
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.012	0.014	0.012	0.017
DW	1.97	1.79	2.06	3.14
Constant	0.009 (1.75)	0.001 (0.11)	0.014 (2.07)	47.395 (0.52)
k^*	0.312 (1.50)	0.473 (0.42)	0.194 (0.88)	-0.204 (0.11)
r^*	0.432 (2.61)	-0.186 (0.24)	0.643 (3.00)	0.503 (0.92)
USA	0.016 (2.18)	0.009 (0.44)	0.014 (1.79)	-81.436 (0.53)
FRA	0.000 (0.06)	0.000 (0.03)	0.000 (0.03)	5.538 (0.05)
GER	0.004 (0.50)	0.000 (0.01)	0.007 (0.84)	-25.812 (0.23)
GBR	0.004 (0.66)	0.004 (0.27)	0.003 (0.40)	-48.127 (0.36)
DEN	0.014 (1.98)	0.018 (0.99)	0.009 (1.03)	-42.228 (0.41)
SWE	0.009 (1.28)	0.014 (0.60)	0.010 (1.10)	-0.812 (0.01)
ρ			0.119 (0.69)	1.000 (0.89)
Endogeniety test p-value	1.00	—	1.00	—
Exclusion test p-value	.00	.31	1.00	.99

Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
Instrument list: ln(Y/L), ln(Y/K), ln(Y/R), and country dummies.
Endogeneity test is p-value for Hausman specification test, OLS null versus IV alternative.
Exclusion test is p-value for F-test, null with dummies equal to zero versus unrestricted alternative.
See text.
Sources:
See appendix.

Table 4: Factor Accumulation Model with Catching Up, 1870–1914

	(16)	(17)	(18)	(19)
Method	OLS	AR1	OLS	AR1
Sample	Panel	Panel	Panel	Panel
NOBS	49	42	49	42
R squared	.63	.71	.63	.71
R squared adjusted	.21	.36	.22	.36
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.013	0.011	0.013	0.011
DW	1.67	2.24	1.68	2.21
Constant	0.012 (0.90)	0.013 (0.70)	0.011 (1.49)	0.019 (2.05)
*k**	0.472 (2.53)	0.267 (1.44)	0.510 (2.67)	0.281 (1.48)
*r**	0.419 (2.52)	0.621 (2.95)	0.445 (2.89)	0.658 (3.31)
a(0)			-0.001 (0.48)	0.000 (0.13)
y(0)	-0.001 (0.15)	-0.003 (0.36)		
ρ		0.303 (2.08)		0.289 (2.07)
Endogeniety test p-value	.40	.91	.61	.93

	(20)	(21)	(22)	(23)
Method	OLS	AR1	OLS	AR1
Sample	Panel	Panel	Panel	Panel
NOBS	49	42	49	42
R squared	.63	.71	.53	.61
R squared adjusted	.20	.35	.03	.17
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.013	0.012	0.014	0.013
DW	1.67	2.26	1.48	2.23
Constant	0.002 (0.09)	0.005 (0.18)	-0.010 (0.49)	-0.023 (0.68)
*k**	0.502 (2.60)	0.278 (1.46)		
*r**	0.416 (2.49)	0.623 (2.92)		
a(0)	-0.002 (0.65)	-0.001 (0.36)	0.000 (0.09)	0.000 (0.00)
y(0)	-0.003 (0.46)	-0.004 (0.51)	-0.009 (1.52)	-0.015 (1.51)
ρ		0.311 (2.02)		0.387 (2.31)
Endogeniety test p-value	.42	.94	.00	.70
Restriction test p-value	.00	.00	.00	.00

Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
Instrument list: ln(Y/L), ln(Y/K), ln(Y/R), and country dummies.
TFP calculated as lny - alnk - blnr, with coefficients from an AR1 regression of lny on lnk and lnr.
Endogeneity test is p-value for Hausman specification test, OLS null versus IV alternative.
Restriction test is p-value for F-test, with null coefficients of a(0) and y(0) sum to zero.
See text.
Sources:
See appendix.

Table 5: Factor Accumulation Model with Human Capital Effects, 1870–1914

	(24)	(25)
Method	OLS	AR1
Sample	Panel	Panel
NOBS	49	42
R squared	.63	.71
R squared adjusted	.22	.36
Mean Dep. Var.	0.014	0.014
SEE	0.013	0.011
DW	1.66	2.22
Constant	0.016 (3.32)	0.022 (3.31)
*k**	0.483 (2.69)	0.277 (1.49)
*r**	0.450 (2.88)	0.671 (3.39)
ln(sH)	0.005 (0.48)	0.006 (0.39)
ρ		0.284 (2.04)
Endogeniety test p-value	.78	.93

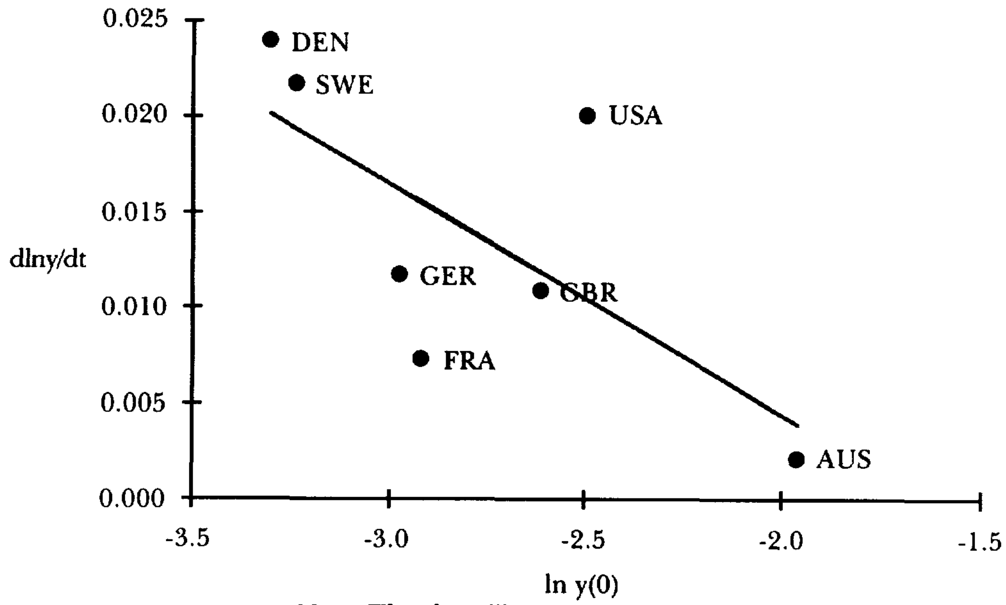
Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
Instrument list: ln(Y/L), ln(Y/K), ln(Y/R), and country dummies.
Endogeneity test is p-value for Hausman specification test, OLS null versus IV alternative.
See text.
Sources:
See appendix.

Table 6: Factor Accumulation Model with Terms-of-Trade Effects, 1870–1914

	(25)	(27)	(28)	(29)
Method	OLS	AR1	OLS	AR1
Sample	Panel	Panel	Panel	Panel
NOBS	49	42	49	42
R squared	.63	.71	.64	.71
R squared adjusted	.23	.36	.22	.35
Mean Dep. Var.	0.014	0.014	0.014	0.014
SEE	0.013	0.011	0.013	0.012
DW	1.75	2.21	1.79	2.27
Constant	0.014 (4.95)	0.020 (4.98)	0.014 (4.86)	0.020 (5.02)
*k**	0.456 (2.53)	0.275 (1.47)	0.463 (2.55)	0.283 (1.49)
*r**	0.428 (2.87)	0.650 (3.37)	0.422 (2.80)	0.665 (3.42)
*tot**	0.135 (0.93)	0.011 (0.09)		
tot . NW*			0.051 (0.24)	-0.076 (0.42)
tot . OW*			0.210 (1.05)	0.108 (0.62)
ρ		0.285 (2.02)		0.263 (1.84)
Endogeniety test p-value	.79	.89	.88	.96

Notes:
The dependent variable is dlny/dt, the growth rate of output per worker (y=Y/L).
Instrument list: ln(Y/L), ln(Y/K), ln(Y/R), and country dummies.
Endogeneity test is p-value for Hausman specification test, OLS null versus IV alternative.
See text.
Sources:
See appendix.

Figure 1: Beta Convergence, 1870–1914



Note: The chart illustrates regression (3), Table 1.

Figure 2: Sigma Convergence, 1870–1914

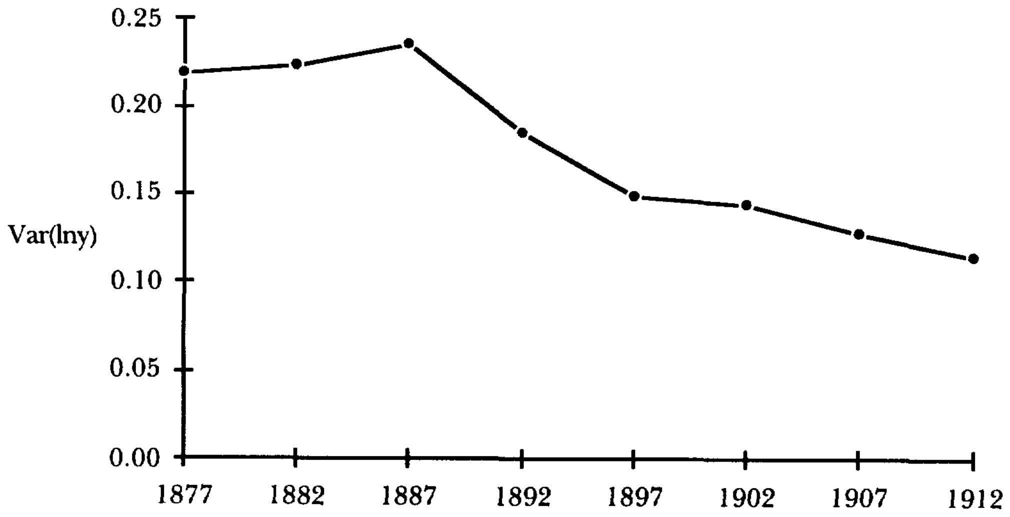


Figure 3: The basic model with labor and capital mobility

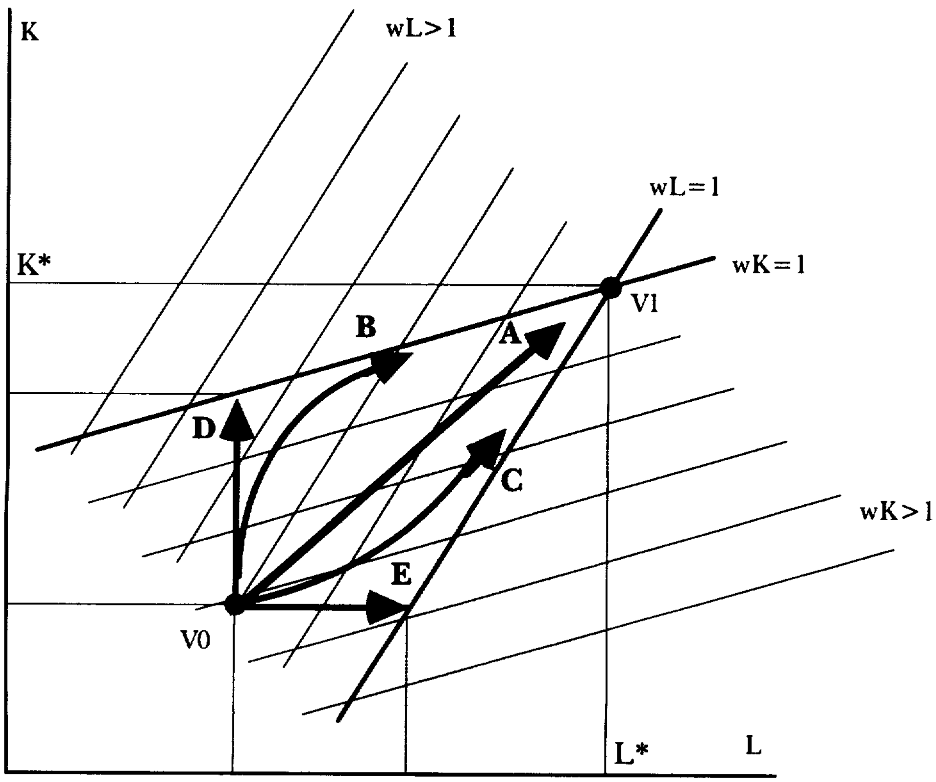


Figure 4: Sigma Convergence, Factor Accumulation Model

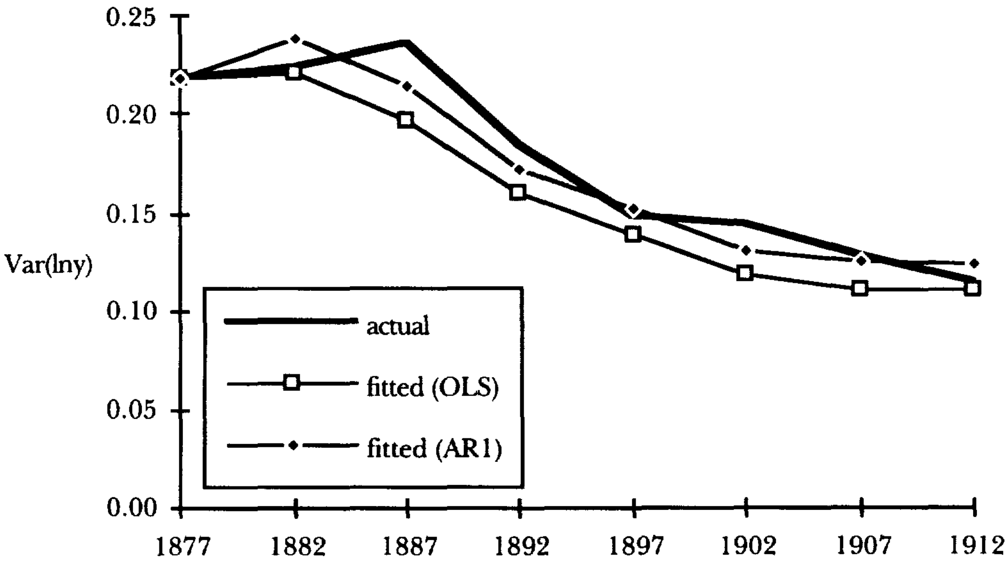


Figure 5: Sigma Convergence, Fitted Component, Catching Up

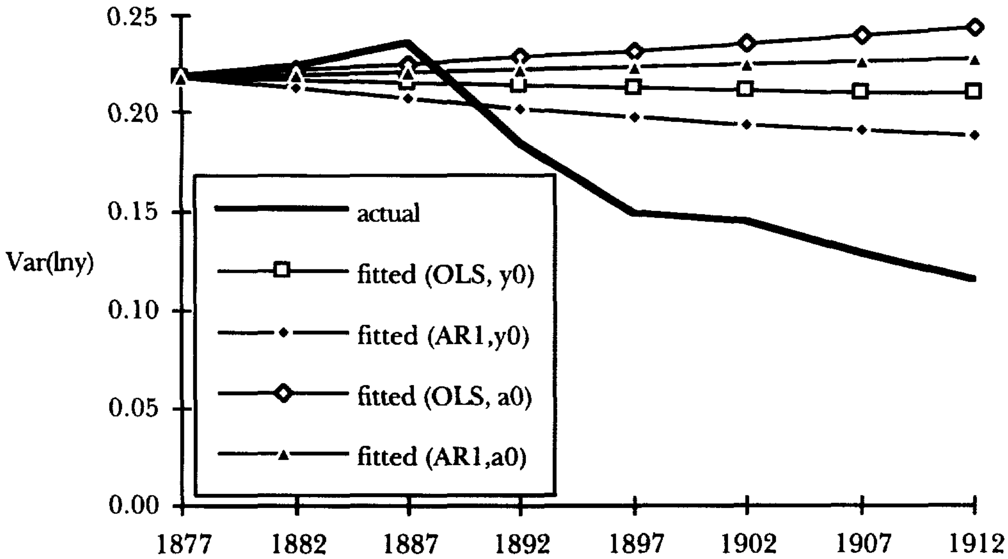


Figure 6: Sigma Convergence, Fitted Component, Human Capital

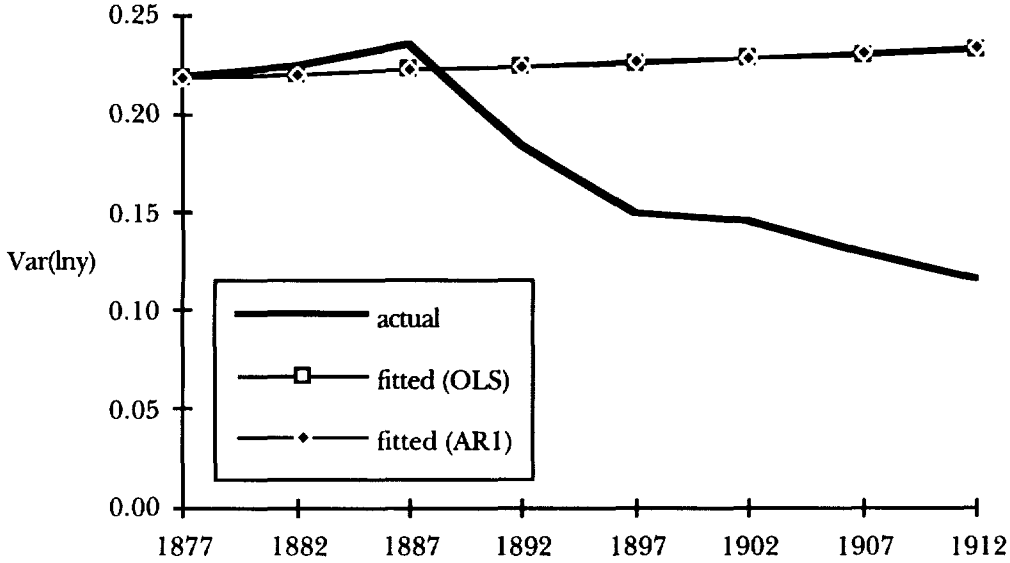


Figure 7: Sigma Convergence, Fitted Component, Terms-of Trade