NBER WORKING PAPER SERIES

CONVERGENCE AND INTERNATIONAL FACTOR FLOWS IN THEORY AND HISTORY

Alan M. Taylor

Working Paper 5798

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 1996

I thank Moses Abramovitz, N.F.R. Crafts, Ronald Findlay, Timothy Hatton, Ian McLean, Boaz Moselle, Cormac Ó Gráda, Kevin O'Rourke, Sherman Robinson, and session participants at the 1996 AEA meetings in San Francisco for helpful discussions on this subject. All errors are mine alone. This paper is part of NBER's research program in Development of the American Economy. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

NBER Working Paper 5798
October 1996

CONVERGENCE AND INTERNATIONAL FACTOR FLOWS IN THEORY AND HISTORY

ABSTRACT

Standard neoclassical growth models rarely admit international factor mobility: convergence may result from factor accumulation in a closed economy, or from technology transfer. Conventional models are thus poorly equipped to explain the contribution of international factor flows to convergence in history. A general model with many goods, and multiple mobile and fixed factors is developed. In response to recent historical research, a four-factor case is studied, with labor, capital, and resources as potentially mobile factors, and land fixed. The model is then explored in the context of recent historical analyses of the sources of long-run convergence and divergence.

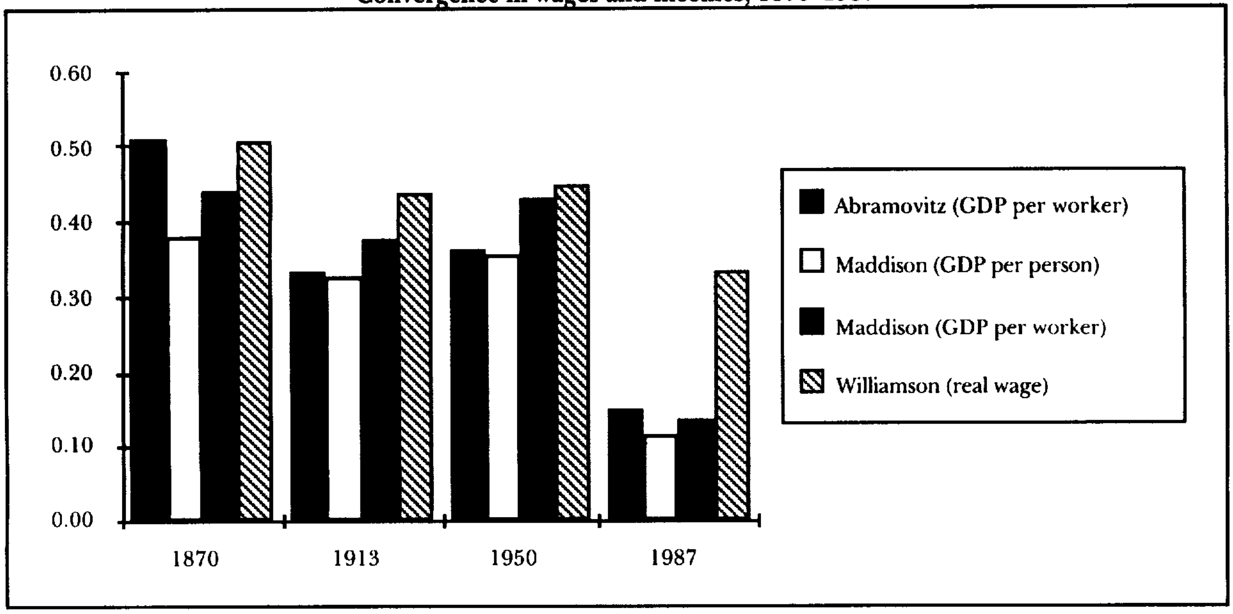
Alan M. Taylor
Department of Economics
Northwestern University
2003 Sheridan Road
Evanston, IL 60208-2600
and NBER
amt@nwu.edu

1. HISTORY

The recent debate over convergence and economic growth, though largely conducted by macroeconomists, is really a discovery that economic history matters. Gregory Mankiw's (1995) capable new survey of this field was entitled "The Growth of Nations," two centuries after the question of what made a nation wealthy made its mark. As Joel Mokyr tellingly observes, the two issues of wealth and growth are inseparable—and the link is history: to say a nation is rich is to say it grew in the past, and this, at once, describes everything but explains nothing (Mokyr 1992, 1). Yet only occasionally has the growth and convergence literature made an impact in economic history, and the feedback from economic historians to the macroeconomists has also been sporadic. What challenges does history bring to the convergence debate? The debate itself was started by an economic historian, Moses Abramovitz (1986), who rightly took the long view. Though recent work in empirical growth has been content to work on the more accessible and data-abundant post-1950 global experience, Abramovitz suggested we tackle a much harder question: explaining the relative wealth of nations in the last two centuries of the post-Industrial Revolution era, that is, comparative economic growth over the very long run since Adam Smith first advanced his thesis.

Historians are only beginning to grapple with these questions, but the findings raise many questions about how we think growth and convergence processes work. In this paper I review some basic empirical evidence and consider the question of which models are relevant. I suggest that we need to consider alternatives to both the technology-transfer models of productivity catch-up in the Gerschenkronian tradition (Gerschenkron 1962), and the closed-economy models of accumulation in the Solow-Swan tradition (Solow 1956; Swan 1956). Before 1950, the last great epoch of global convergence was 1870–1913. Any theory which ignores the massive migration of factors in this period is probably deficient: empirical evidence suggests that these flows mattered a lot for convergence, and that factor accumulation (including these flows) was the main source of convergence. In contrast, technology transfer appears to have mattered very little. The conclusion that needs to be drawn is that the mechanics of economic growth may be very different in different eras and for different groups of countries. Economists need a tool kit of different growth models which encompass these very different conditions. The present model is one part of that tool kit.

Figure 1
Convergence in wages and incomes, 1870–1987



Notes: The chart shows coefficient of variation (variance divided by mean squared). Abramovitz's and Maddison's samples: Australia; Austria; Belgium; Canada; Denmark; Finland; France; Germany; Italy; Japan; Netherlands; Norway; Sweden; Switzerland; United Kingdom; United States. Williamson's sample: Argentina; Australia; Canada; United States; Belgium; Denmark; France; Germany; Great Britain; Ireland; Italy; Netherlands; Norway; Spain; Sweden; Brazil; Portugal.
Sources: GDP per worker from Abramovitz (1986); GDP per worker and per person from Maddison (1991); real wages from Williamson (1995).

What is the empirical record of convergence since the mid-nineteenth century? Figure 1 draws on the data of Maddison, Abramovitz, and Williamson to show that convergence has been neither continuous nor uniform. The chart shows the dispersion (coefficient of variation) of either incomes or real wages, and thus tracks σ-convergence for a group of about 15 economies, most now developed but some not. By this reckoning we need to explain four episodes: an initial dispersion in the mid-nineteenth century (phase 1); an era of convergence 1870–1913 (phase 2); an era of divergence in the interwar period (phase 3); and a phase of very rapid convergence after 1950 (phase 4). This chronology or typology of phases has already been suggested by all the authors just cited. I motivate my model by arguing that international factor movements might have played a large and neglected role in all four episodes—a view which has been advance elsewhere, and which demands more theoretical and empirical analysis.

With respect to labor movements and convergence, Jeffrey Williamson (1995) has argued that the appearance of mass migration in the "Greater Atlantic Economy" can explain the commencement of rapid convergence circa 1870, suggesting that lowered transport and information costs in the migration process made the critical difference between phases 1 and 2. In addition, the emergence of quotas and restrictions, and other deterrents to migration in the interwar period (higher costs and uncertainty) helps explain the cessation of that convergence process and the divergence in phase 3. Estimates suggest that mass migration can explain a large part of convergence 1870–1913, even allowing for the fact that capital often chased labor to the New World, which in itself was an offsetting anti-convergence trend (Taylor and Williamson 1997). I read the Williamson approach, recently restated (Williamson 1996), as follows: it stresses changes in international labor mobility circa 1850–1950 as determining convergence; it treats international capital mobility as being much more uniform over that period; it assumes resources to be essentially fixed, though with endogenously expanding New World frontiers being a possible offset to convergence; it downplays technology transfer and human capital accumulation which it sees as having less import at the turn of century; it interprets the resumption of convergence in phase 4 as being due to the arrival of new pro-convergence forces like technology transfer, human capital accumulation, and the like.

With respect to resources, Gavin Wright (1990) has provided another potential explanation of convergence patterns. In the Wright story, countries which possess *and exploit* abundant resources in the late-nineteenth century enjoy a growth advantage, the canonical case being the United States which gained international manufacturing leadership based on a comparative advantage related to certain minerals, oil, and other natural resources. However, by the mid-to-late twentieth century, such resource endowments were no longer providing country-specific advantages; first, because more countries had found and exploited resources of their own; but second, and possibly more important, all countries could enjoy access to these resources since they had become internationally tradable. A country like Japan was no longer penalized for not having metalliferous ores; it could simply import large mountains of ore (literally) from

Australia. Thus, the mobility of resources became a pro-convergence force in phase 4 where previously it had been absent in phases 1, 2 and 3. In addition, Wright also emphasizes the emergence of other pro-convergence forces in phase 4, such as research and development, technology transfer, and human capital accumulation (Nelson and Wright 1992).

Are the Williamson and Wright theories rivals or complements? Can they be reconciled with theory and evidence? What might be missing from existing models of convergence? A theory informed by the Williamson-Wright views of globalization via international factor mobility might explain a great deal of the convergence history recorded in the four phases, with a simple chronology. In such a setting, capital mobility is in the background, more or less uniform over time. Labor mobility reaches its peak in the age of mass migration, promoting convergence for a time, but virtually disappears after that. Resources initially convey comparative advantage and resource-deepening is country specific, until the modern-day tradability of resource makes them mobile and promotes convergence. Is such a story reasonable?

In the next section I develop a model that rigorously demonstrates how factor mobility might drive convergence. A simple version of the model with four factors (labor, capital, land, resources) is then developed which places the above story on a firm theoretical footing. As for whether this approach is justified, I conclude with some discussion of the current state of the empirical literature as it impinges on the two key questions: what do we know about the evolution of international factor mobility over time? and what do we know about the role of factor accumulation in generating convergence?

2. THEORY

In this section I develop a model of convergence driven by the globalization of factor markets. The model has many goods and factors, with the flexibility to allow for some factors being fixed (sector specific) and others internationally (and intersectorally) mobile. Factor migration depends on adjustment costs, so factors are only quasi-mobile, an abstraction which captures the slow adjustment of international factor endowments to disequilibria. I then explore the model with a one-good, four-factor case, the fixed factor being land, and the mobile factors being labor, capital, and resources. Simple diagrams suffice to illustrate the model dynamics. Although this macroeconomic production-function approach is a special case, its relation to more general many-good, many-factor models and factor proportions issues is considered; I show that general applicability hinges on the degree of substitution in the economy , as captured in the convexity properties of the revenue function. The required condition is quite weak, but a notable theory of trade, the simple Heckscher-Ohlin model, fails to pass the test. Lastly, I show that an assumption of fixed land stocks might be relaxed to admit endogenous frontier dynamics in a manner consistent with Findlay (1995).

2.1. A General Model

Production takes place in a small open economy. Output in each of N sectors is denoted $(x_1,\ldots, x_N)$. Each good is tradable and the output price of good i is equal to the world price p_i. Each sector employs inputs drawn from a set of $M>0$ internationally mobile factors and a set of $P>0$ fixed or specific factors. The total domestic endowment of the mobile factors is denoted $(v_1,\ldots, v_M)$. The total domestic endowment of the specific factors is denoted $(v^F{}_1,\ldots, v^F{}_P)$. Without loss of generality, each mobile factor v_j will be measured in such a way that its world price is normalized to unity. Interest will focus on factor inputs as a part of product in the country of use, rather than on factor rewards as a part of income or expenditure in a foreign country.[1] The sectoral production functions will be assumed to be constant returns to scale of the usual type,

(1) $x_i = p_i f_i(v_{ij}, v^F{}_{ij})$,

where $\partial f_i/\partial v_{ij} > 0$, $\partial f_i/\partial v^f{}_{ij} > 0$, $\partial^2 f_i/\partial v_{ij}{}^2 < 0$, $\partial^2 f_i/\partial v^f{}_{ij}{}^2 < 0$, for all i, j.

It is well known from the theory of trade that the basic equilibrium properties of such an economy are succinctly summarized in the revenue function $\Re(p, v)$ where $p = (p_i)$ is the output price vector, and $v = (v_i, v^F{}_i)$ is the input vector, or total factor endowment vector, for the economy as a whole (Dixit and Norman 1980, 43). We may note several useful results. First, factor prices are given by

(2) $w_j = \partial\Re/\partial v_j = w_j(p, v)$ for all j.

---

[1] For example, ore imports from Australia to Japan are considered as part of Japanese output, and no account is taken of current account transactions. Similarly, Italian laborer's wages in the U.S. would be considered in sum as part of labor's share of U.S. output, not as part of income when used in remittances to Italy. And, in the case of capital, say, British investments in Argentina are valued as a contribution to Argentine output not British income.

Moreover, the revenue function $\mathfrak{R}$ is concave in v (Dixit and Norman 1980, 35). Thus, the corresponding Hessian matrix of second derivatives H_{ij} has the property

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

For our purposes the final goods prices p_i and the fixed factors $v^F{}_j$ will be exogenous parameters of the model, and we will rewrite the function $\mathfrak{R}$ as a function of only the endogenous mobile factor endowments in the form $\mathfrak{R} = \mathfrak{R}(v_1,\ldots,v_n)$. Another property of the revenue function is

(4) $$\mathfrak{R}_{vv}v = 0,$$

so that the Hessian matrix H_{ij} at (3) has rank at most equal to M+P–1 and is certainly not negative definite. For a determinate equilibrium we will require that H_{ij} has this maximal rank, a condition requiring a precise form of "sufficient substitutability" in production (Dixit and Norman 1980, 30–35),[2] which guarantees, by (4), that the upper-left diagonal block of H_{ij} is negative definite, which implies

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

World financial markets are assumed to be governed by a fixed interest rate r, but to allow for the realistic case of non-instantaneous adjustment of internationally mobile factor stocks, a standard adjustment cost function for each mobile factor will be introduced, thus allowing for a form of factor quasi-mobility. Mobile factors have unit prices on world factor markets, prices w_i in domestic markets, and factor flows (migrations) 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.

Let $b_i(t)$ denote the rational-expectations marginal benefit of an incremental inflow of factor i at an arbitrary time t. Working in a continuous-time framework, $b_i(t)$

---

[2] In the Dixit-Norman terminology, we don't want the revenue function to have a graph with "flat" portions. For example, the rank condition would *not* be satisfied in the Heckscher-Ohlin 2×2model because factor prices $w=\mathfrak{R}_v$ do not depend on factor endowments v, but only on prices, $w=w(p)$; thus, $\mathfrak{R}_{vv}=0$ has zero rank. Note that the condition P>0 is not satisfied: there are no specific factors. The sufficient substitutability condition is discussed below for this and other models.

is given by the present value of the difference between national and world factor rewards:

$$(6) \qquad b_i(t) = \int_{s=t}^{\infty} (w_i(s) - 1)\, e^{-rs}\, ds \qquad \text{for } i = 1,\ldots, n.$$

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

$$(7) \qquad c_i(t) = \eta'_i(m_i(t)).$$

In equilibrium, flows will be such that $b_i(t) = c_i(t)$ for all i and t, so that, equating (6) and (7), we obtain $m_i = \psi_i(b_i)$, where ψ_i is the inverse of η'_i. We may admit a general form of 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, $dv_i/dt = m_i - \delta_i v_i$. For practical purposes in this paper, we shall restrict attention to renewable (or durable) factors with $\delta_i = 0$, such as labor or capital, and non-renewable (or non-durable) factors with $\delta_i = 1$ such as intermediate resource inputs, like coal, oil or minerals (where the instantaneous use and destruction rate is equal to the flow value).[3] Finally, by differentiating (6) we can find the dynamical system governing v_i and b_i,

$$(8) \qquad db_i/dt = -[w_i(v(t)) - 1] + rb_i(t),$$

$$dv_i/dt = \psi_i(b_i(t)) - \delta_i\, v_i(t), \qquad \text{for all } i,$$

$$\text{where (by the properties of } \eta) \qquad \psi_i(0)=0, \text{ and } \psi_i'>0 .$$

An equilibrium (b_i^*, v_i^*) of the dynamical system (8) must satisfy

$$(9) \qquad \psi(b_i^*) - \delta_i = 0,$$

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

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 $\Re$ and η. The

---

[3] The depreciation parameter is thus a useful abstraction since it allows the model to deal in a standardized way with various factor types, including resources. The stock-flow distinction is important. Certain resources are fixed stocks, like renewable agricultural land, say. Other resources are mobile, but only in flow form; for example, Australia does not export a renewable ore-field to Japan, but rather a stream of non-renewable ores as an annual flow. More generally, we can think of stock variables like labor and capital having low δ_i (but not exactly zero). For example, labor depreciates via mortality, capital by wear and tear or obsolescence. In principle, the model could also be extended to include exogenous labor force growth, exogenous technical change, steady-state domestic saving, and a variety of other equilibrium properties. However, the stripped-down version suffices to illustrate the basic form of a convergence model with many mobile factors.

equations (9) say that in steady state: (a) inflow rates must equal the replacement rates for the factor (i.e., no flows for durable factors, and flows equal to per period use for non-durable factors); and (b) the home-world factor-price gap must equal the annualized value of the marginal net-benefit of factor movement.[4]

In order to determine the local behavior of the system in a neighborhood of the equilibrium (b_i^*, v_i^*) we linearize the dynamical system (4), using ($\mathbf{b}'$, $\mathbf{v}'$) as local coordinates in the neighborhood of ($\mathbf{b}^*$, $\mathbf{v}^*$), to obtain:

$$(10) \quad \begin{pmatrix} d\mathbf{b}'/dt \\ d\mathbf{v}'/dt \end{pmatrix} = \begin{pmatrix} r\mathbf{I} & \mathbf{A} \\ \mathbf{J} & -\mathbf{D} \end{pmatrix} \begin{pmatrix} \mathbf{b}' \\ \mathbf{v}' \end{pmatrix}$$

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

$\mathbf{A} = (A_{ij})$, positive definite and symmetric by (5)

$\mathbf{J} = \text{diag}(\psi_i'(b_i^*))$, positive definite and symmetric by (8),

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

This linear system may be rearranged to provide the following second-order differential equation in $\mathbf{v}'$:

$$(11) \quad d^2\mathbf{v}'/dt^2 + (\mathbf{D} - r\mathbf{I})\, d\mathbf{v}'/dt - (\mathbf{JA} + r\mathbf{D})\,\mathbf{v}' = 0$$

The local dynamics of the system can be investigated through the characteristic equation,

$$(12) \quad 0 = \det(\lambda^2\mathbf{I} + \lambda(\mathbf{D} - r\mathbf{I}) - (\mathbf{JA} + r\mathbf{D}))$$
$$= \det((\lambda - r)(\lambda\mathbf{I} - r\mathbf{D}) - \mathbf{JA}).$$

In the case $\mathbf{D} = 0$, the dynamics are easily understood. The characteristic equation takes the form $\det((\lambda - r)\lambda\mathbf{I} - \mathbf{JA}) = 0$, so that eigenvalues λ satisfy $\lambda(\lambda - r) = \mu \in \text{eig}\,\mathbf{JA}$. Recall that $\mathbf{J}$ and $\mathbf{A}$ are positive definite, so $\mu > 0$, and clearly such λ occur in (+,–) pairs for each μ, indicating that the system has n stable (–) and n unstable (+) eigenvalues.

In the case $\mathbf{D} = \mathbf{I}$, the dynamics depend on the parameters. The characteristic equation becomes $\det((\lambda - r)^2\mathbf{I} - \mathbf{JA}) = 0$, and now the eigenvalues λ satisfy $(\lambda - r)^2 = \mu$, or equivalently $\lambda = r \pm \mu$ for $\mu \in \text{eig}\,\mathbf{JA}$. Thus, only for r sufficiently small will we

[4] The equation $w_i(v^*) - 1 = rb_i^*$ is equivalent to $r^{-1}(w_i(v^*) - 1) = \eta'_i(m_i^*)$, which says that the present-value marginal benefit of factor movement equals marginal transport cost, an intuitive result.

have n stable eigenvalues. This property holds for general **D**, as the local approximation to (12) when r is small generates n stable eigenvalues close to those in the case $\mathbf{D} = 0$.[5]

In what follows we shall assume that n (+,–) eigenvalue pairs do indeed exist. The n negative eigenvalues generate an n-dimensional vector subspace which is the stable set of this system. As is customary in q-theory, our attention will be focused on the perfect-foresight or rational-expectations solutions which lie in this stable set.[6] The stable set corresponds to the stable manifold of the non-linear system (8) in the neighborhood of the equilibrium. The stable manifold is an n-manifold in $\mathbf{R}^{2n}$, and the dynamics on the stable set are locally determined by the n negative eigenvalues $\alpha_i = \alpha_i(\mathbf{J},\mathbf{D},\mathbf{A},r)$, which are commonly called the *speeds of adjustment* of the system in its normal form.

In the present application, for the case when $\mathbf{D} = 0$, the speeds of adjustment of the system satisfy $\lambda(\lambda - r) = \mu \in \text{eig}\,\mathbf{JA}$. Hence, the stable speeds of adjustment satisfy $2\lambda = r - \sqrt{r^2 + 4\mu}$, and it is clear that $|\lambda|$ is an increasing function of μ, which is an increasing function of each J_i.[7] 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

5 In the case $\mathbf{D} = 0$ the local dynamics of the system may be understood by a careful choice of local coordinates. Consider the matrix $\Lambda = \mathbf{JA}$. It is clear from (10) that Λ is positive definite and symmetric. Thus, we may find a basis with respect to which Λ is diagonal and positive definite. Let the coordinates in this basis be written $\mathbf{v}''$, and consider the dynamical system (11) with respect to this basis. The new dynamical system is separable in each coordinate, $\Delta^2 v''_i - r\,\Delta v''_i - \Lambda_i v''_i = 0$. Since $\Lambda_i > 0$ for all i, the characteristic equation of this differential equation will yield a (+,–) real eigenvalue pair in each coordinate.

6 We reject explosive solutions off the stable manifold corresponding to positive eigenvalues since these will entail, in the general (non-linear) system, the eventually futile movement of capital out of a sector which is devoid of capital, whereupon the solution breaks down in the fashion described by Mussa (1978).

7 Let $\mathbf{B}=\mathbf{JA}$, with $q=\mathbf{x}'\mathbf{B}\mathbf{x}$ a quadratic form. Let $\mathbf{H}=\mathbf{J}^{1/2}=\text{diag}(J_i^{1/2})$. Let $\mathbf{H}$ generate a basis change, so that $\mathbf{JA}$ transforms to $\mathbf{C}=\mathbf{HAH}$, and $\mathbf{y}=\mathbf{H}^{-1}\mathbf{x}$. The quadratic form $q=\mathbf{x}'\mathbf{B}\mathbf{x}$ becomes $q=\mathbf{y}'\mathbf{C}\mathbf{y}$ in the new coordinates, and it is clear that its minimal eigenvalue is increasing in J_i for fixed $\mathbf{A}$ (consider the minimization of $\mathbf{y}'\mathbf{C}\mathbf{y}$ over $|\mathbf{y}|=1$). Deleting the eigenvector-subspace of the minimal eigenvalue and proceeding by induction suffices to show that every eigenvalue of q, and hence of **B**, is increasing in J_i.

does $J_i = \psi'_i$; thus increased factor mobility, in the form of declining transport costs, increases the speed of adjustment of the system in the neighborhood of equilibrium.

2.2. A basic model: a four-factor world

The above section has presented a general model of growth through factor migration in a small open economy. However, as it stands, the model is far too general to be of practical use. In this section we 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 mobile resource input (say, minerals), and F is a fixed resource input (say, land).[8] CRS implies that $\alpha + \beta + \gamma + \theta = 1$. Only L, K and R are internationally mobile, and factor durability is characterized by $\delta_L = \delta_K = 0$ (capital and labor renewable) and $\delta_R = 1$ (mobile resources are non-renewable). This framework allows us to explore the model under production characteristics similar to those used in conventional growth models, whilst allowing for various regimes of international factor mobility.

In this special case, the theory simplifies to the following "basic model" utilized in the remainder of the paper. The equilibrium equations are

$$\begin{aligned} (13)\quad & b_L^* = 0, \\ & b_K^* = 0, \\ & \psi(b_R^*) = 1, \\ & w_L(L^*,K^*,R^*) = 1, \\ & w_K(L^*,K^*,R^*) = 1, \\ & w_R(L^*,K^*,R^*) - 1 = rb_R^*. \end{aligned}$$

The linearized system takes the following form, with the ψ' evaluated at the equilibrium:

[8] In a later section I consider the possibility of an endogenously determined land stock in the context of frontier dynamics following Findlay (1995, chapter 5).

$$(14)\quad \frac{d}{dt}\begin{pmatrix} b_L \\ b_K \\ b_R \\ L \\ K \\ R \end{pmatrix} = \begin{pmatrix} r & 0 & 0 & A_{LL} & A_{LK} & A_{LR} \\ 0 & r & 0 & A_{KL} & A_{KK} & A_{KR} \\ 0 & 0 & r & A_{RL} & A_{RK} & A_{RR} \\ \psi'_L & 0 & 0 & 0 & 0 & 0 \\ 0 & \psi'_K & 0 & 0 & 0 & 0 \\ 0 & 0 & \psi'_R & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} b_L \\ b_K \\ b_R \\ L \\ K \\ R \end{pmatrix}.$$

We may note that for the Cobb-Douglas production technology A here takes the form

$$(15)\quad A = \begin{pmatrix} \alpha(1-\alpha)X/L^2 & -\alpha\beta X/KL & -\alpha\gamma X/RL \\ -\alpha\beta X/KL & \beta(1-\beta)X/K^2 & -\beta\gamma X/KR \\ -\alpha\gamma X/RL & -\beta\gamma X/KR & \gamma(1-\gamma)X/R^2 \end{pmatrix},$$

whereby

$$(16)\quad \det A = \frac{X^3}{L^2K^2R^2}\det\begin{pmatrix} \alpha(1-\alpha) & -\alpha\beta & -\alpha\gamma \\ -\alpha\beta & \beta(1-\beta) & -\beta\gamma \\ -\alpha\gamma & -\beta\gamma & \gamma(1-\gamma) \end{pmatrix} = \frac{X^3}{L^2K^2R^2}\alpha\beta\gamma\theta.$$

It follows that the "sufficient substitutability" condition required to generate a positive definite A at (5) here takes the form that each budget share be greater than zero. That α, β and γ be greater than zero is a trivial requirement if factor mobility is to have any meaning for all three mobile factors L, K and R. If any one had a zero input share in the production function then we could just delete it from the analysis. The additional condition $\theta > 0$ is simple, if not intuitively obvious. If there were no fixed factor in the small country in this model ($\theta = 0$), then, with CRS in L, K and R, the country could simply replicate itself at an increasingly larger scale by importing proportionate amounts of all three mobile factors from the world economy. With factor prices then homogenous of degree zero in the three factor stocks, there could be no determinate equilibrium. Even if domestic factor prices equaled world factor prices at some endowment (L,K,R), there would then be an infinity of endowment equilibria of the form $(\lambda L, \lambda K, \lambda R)$ for all $\lambda > 0$.

2.3. Exploring the basic model: capital and labor mobility

We may now see how the mechanics of the model work and a useful illustrative example is provided by the case of two-factor (capital and labor) mobility. Here the dynamical system takes the form

$$(17)\quad b_L^* = 0,$$

$$b_K^* = 0,$$

$w_L(L^*,K^*) = 1,$

$w_K(L^*,K^*) = 1,$

The linearized system takes the following form, with the ψ' evaluated at the equilibrium:

$$(18)\quad \frac{d}{dt}\begin{pmatrix} b_L \\ b_K \\ L \\ K \end{pmatrix} = \begin{pmatrix} r & 0 & A_{LL} & A_{LK} \\ 0 & r & A_{KL} & A_{KK} \\ \psi'_L & 0 & 0 & 0 \\ 0 & \psi'_K & 0 & 0 \end{pmatrix}\begin{pmatrix} b_L \\ b_K \\ L \\ K \end{pmatrix}.$$

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

$$(19)\quad w_L = \alpha L^{\alpha-1}K^{\beta}R^{\gamma}F^{\theta} = \alpha(X/L);$$

$$w_K = \beta L^{\alpha}K^{\beta-1}R^{\gamma}F^{\theta} = \beta(X/K);$$

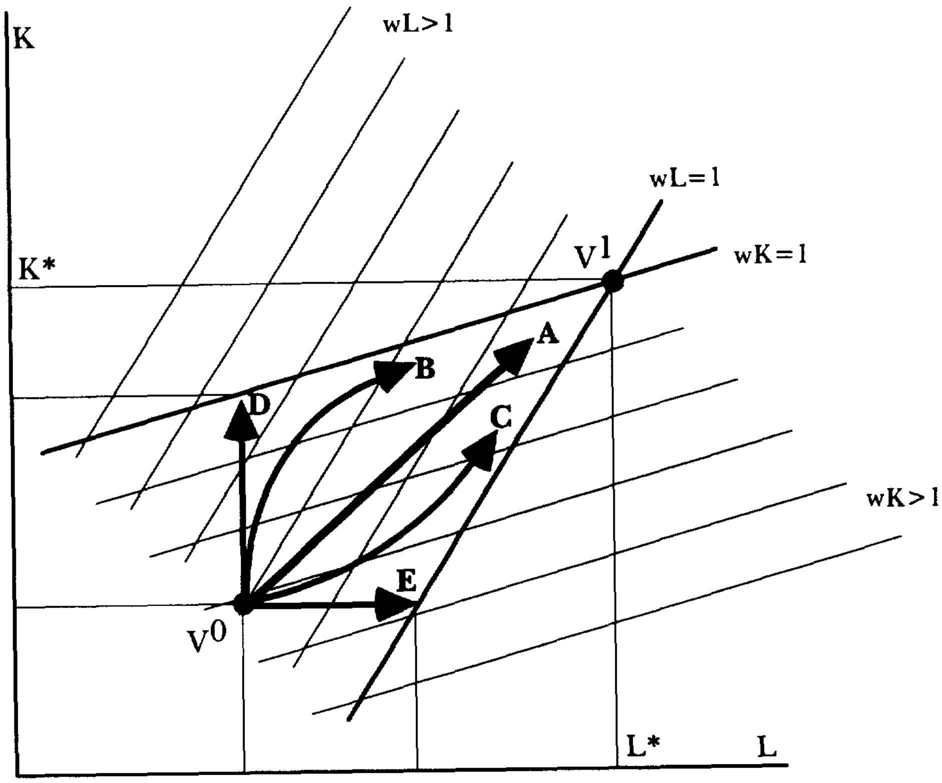
$$w_R = \gamma L^{\alpha}K^{\beta}R^{\gamma-1}F^{\theta} = \gamma(X/R);$$

$$w_F = \theta L^{\alpha}K^{\beta}R^{\gamma}F^{\theta-1} = \theta(X/F).$$

Note that, with the special choice of revenue function, wage and output-per-worker convergence are identical in the basic model. Dynamics may be traced by plotting trajectories in (K, L)-space. We may plot iso-w_L and iso-w_K contours to illustrate the convergence properties of the transitional dynamics, as in Figure 2. Here, an equilibrium at V^1 is shown, and an initial factor endowment is 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, each one corresponding to different adjustment cost functions for K and L. 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 $w_L = 1$ respectively.

The diagram provides various insights about the impact of factor mobility on convergence patterns. A basic finding is that the presence of factor mobility may generate convergence *or* divergence: in Figure 2, along certain trajectories, we temporarily (B), and sometimes perpetually (D), 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

Figure 2
The basic model with labor and capital mobility



introduction of factor mobility may introduce permanent or transitory divergence, and may (or may not) lead to long-run convergence.

This divergence result is an important property of the present model and contrasts with the standard two-factor neoclassical growth model. In the two-factor model international factor mobility promotes convergence (Barro, Mankiw and Sala-i-Martin 1992); this property does not generalize to a model with more factors. The result of the standard two-factor model is of limited historical application. Such a framework is ill-suited for the study of cases characterized by dual-scarce factors, such as the economics of the New World in the nineteenth century (cases which start at points like V^0). Instead, convergence properties are more ambiguous. Convergence depends critically on which factors are mobile and how mobile they are (adjustment costs matter in the dynamic specification); convergence also depends on the prevailing relative factor scarcities (initial conditions imply that the convergence property exhibits path dependence).[9] This theoretical finding implies more challenging targets for empirical research: to assess the impact of factor accumulation on growth, document changing factor endowments over time, and expand studies of international factor market integration to better understand the process of adjustment.

2.4 The general model: factor proportions and the revenue function

The present basic model is a one good abstraction. The general model showed that the same factor convergence dynamics could be built in to a model with many goods. Only with many goods do we escape the macroeconomic focus on aggregate production function modes of growth, only to encounter the trade theorist's concern with factor proportions, diversification, integrated equilibria and the like. Can this transition be a smooth one? Isn't the basic model a rather special case. Here I would simply note that our view of the usefulness of the basic model as an expositional device depends largely on our opinion as to the general applicability of the sufficient substitutability condition required at (5). Some simple models from the trade literature illustrate this issue.

As noted, this condition fails for the simple 2×2 Heckscher-Ohlin model with diversification (Dixit and Norman 1980, 111–14). Here, factor endowments do not affect factor prices, so that $\mathfrak{R}_V = w = w(p)$, and $\mathfrak{R}_{VV}$ is zero, has zero rank, and is not negative definite. This technology fails the test because the revenue function is a "flat" function of endowments in the relevant range, being a linear function of L and K, with $\mathfrak{R} = w_L(p)\, L + w_K(p)\, K$. This is a technology ill-suited to the consideration of equilibria in international factor markets because of indeterminacy: if a given economy had a factor price, say, w_L above world levels, then an unending flow of labor L would have cause to migrate into the economy. This might eventually push the economy out of its diversification cone. However, as consideration of the 2×2×2 Heckscher-Ohlin model shows, for a two-country world there is an infinity of equilibrium factor allocations for the two countries with factor price equalization. In this scenario, the migration model would be undermined by the indeterminate nature factor market equilibrium.

[9] It is easy to show that with a labor-rich, capital-scarce economy, one in a different V^0 position in Figure 2a, the imposition of capital mobility does indeed generate convergence, showing that the narrow conventional result is here preserved as a special case.

The above problem recurs in the n×n Heckscher-Ohlin model, but less troublesome is the more general m×n Heckscher-Ohlin model, where the number of factors m is greater than the number of goods n. As Findlay (1995, 23–24) shows, this model has a "price" system $A^T w=P$ which is "underdetermined" (n equations in m unknowns) and a "quantity" system $Ax=v$ which is "overdetermined" (m equations in n unknowns), where A is the matrix of technological coefficients. However, the full general equilibrium system is exactly determined,

$$(20) \quad \begin{pmatrix} A^T & 0 \\ 0 & A \end{pmatrix} \begin{pmatrix} w \\ x \end{pmatrix} = \begin{pmatrix} p \\ v \end{pmatrix}$$

As Findlay notes, in this case "everything depends on everything else" and factor prices w will depend, in general, on endowments v. $\mathfrak{R}_{VV}$ is non-null and its rank depends on technological considerations.

The situation is similar in specific factors models where m exceeds n. In the most basic specific factors model, the 3×2 Ricardo-Viner model (Dixit and Norman 1980, 122–25), the factors are mobile labor L, and sector specific capital K and land R. Here factor prices will depend on factor endowments, and the matrix $\mathfrak{R}_{VV}$ has the form

$$(21) \quad \begin{pmatrix} - & + & + \\ + & - & - \\ + & - & - \end{pmatrix}$$

Here, increments in K and R increase the returns to L, and increments in L increase returns to K and R: thus, labor chases capital and land. But labor and capital "avoid"—rather than chase—each other. Additional K lowers the return to R, and vice versa. This technology contrasts with the simple, one-sector, basic model, where the matrix $\mathfrak{R}_{VV}$ has the following form(omitting F, the fourth factor),

$$(22) \quad \begin{pmatrix} - & + & + \\ + & - & + \\ + & + & - \end{pmatrix}$$

Here all factors are gross substitutes in the sense that they chase each other: increases in the stock of one factor raise the returns to all other factors. Aside from "knife-edge" technological scenarios, the 3×2 Ricardo-Viner model always has a non-zero $\mathfrak{R}_{VV}$

matrix, at least of rank 1. Its maximal rank is 2, and it will fail to have that rank only for a limited set of technologies.[10]

In sum, absent the very special case of the "square" Heckscher-Ohlin system, the $\mathfrak{R}_{VV}$ matrix is non-null, and our sufficient substitutability condition will then depend on the specifics of the technology. It may be reasonable, therefore, to proceed with the analysis. If the matrix has correct rank, then only the signs of the off-diagonal elements matter for determining whether factors are "friends" or "enemies": that is, whether they will "chase" or "repel" each other. If all off-diagonal signs are positive, then all factors are "friends" and the one-good model is an adequate abstraction for this idea.[11]

2.5 An extension: Endogenous frontiers

Finally, let me note a simple extension.[12] 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 $\delta \geq 0$, which is close to or equal to zero. 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. In theory, we can abstractly model this phenomenon by having the

---

[10] The Ricardo-Viner model may fail to satisfy the rank condition, say if $\mathfrak{R}_{VV}$ has the form

$$\begin{pmatrix} -4 & +2 & +2 \\ +2 & -1 & -1 \\ +2 & -1 & -1 \end{pmatrix}$$

[11] Of course, more complicated dynamics could emerge with factor repulsion. For example, if capital and land were "enemies" in the nineteenth century United States, as in the 3×2 Ricardo-Viner model, and if land were "mobile" in the endogenous frontier sense of Findlay (1995, chapter 5), then we would expect capital inflows to *discourage* frontier expansion, and frontier expansion to *discourage* capital inflows. This would be an odd proposition given the present historiographical understanding of the frontier process. I discuss the concept of the endogenous frontier in the next section.

[12] This section draws on Taylor (1996d).

mountain come to Mohammed, so to speak: let us consider the trans-frontier land as being in another country, with an opportunity cost δ, and available for movement into production in the domestic economy via a transaction cost function η_R of the usual kind. If the frontier is successively redrawn on the map as this "migration" of land occurs, this scenario now fits exactly the terms of the present model.[13]

The frontier moves so long as $w_R > \delta$, which might be always true, in which case expansion proceeds until all land is absorbed, with $R = R_{max}$, and the frontier is closed. Alternatively, one could posit a position-varying land opportunity cost $\delta(R)$, where land is initially easy to come by, but costs could rise along a Ricardian-style gradient as we approach natural economic or geographic 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.[14] The function $\delta(R)$ may be supposed to asymptote to infinity as R approaches R_{max}, but $\delta(0)$ may be small. This leads to a more refined economic geography.[15]

Land opportunity costs δ now depend on the expansion of the frontier R. The endowments of land, capital, and labor may initially be in equilibrium with no frontier expansion pressure ($w_R = \delta$). Such a situation may describe the United States before

[13] 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 at the *regional* level (in just the same way we have modeled international factor movements here), and then Mohammed could indeed come to the mountain.

[14] Cronon's (1991) account of the evolution of Chicago and the Great West could be said to be underpinned by just such an understanding of economic geography with a moving frontier in a world of regionally integrated markets for land, labor, capital, and goods.

[15] It bears restating that there usually must be some fixed factor in the model to prevent the economy self-replicating itself with indeterminate factor market equilibrium. Here the condition is sidestepped by positing an additional condition on the land variable: its opportunity cost is an increasing function of the cumulative inflow. This obviously negates the problem of needing to impose a fixed factor. Similarly, we could reject the fixed factor requirement if the country were large, and the external opportunity costs for labor or capital (or at least one mobile factor) were a function of cumulative inflows from the rest of the world. This would prevent the economy self-replicating at ever-larger sizes.

the breaching of the Appalachian barrier.[16] Subsequently, various shocks might upset this equilibrium and prompt movement: labor or capital accumulation might result from saving, population growth, or factor migration due to lowered international transportation costs, increasing land scarcity, raising w_R; or exploration of the interior may reduce uncertainty and changes in technology (military, infrastructure, communications, internal transportation) may reduce the costs δ of expanding west. In this manner, exactly the kind of frontier dynamics envisaged by Findlay (1995) can be incorporated into the present model.[17]

3. HISTORY AND THEORY

The previous section has outlined a basic four-factor model of growth through international factor mobility. This section applies the basic model to the *explicandum* which motivated the paper at its introduction: the observed variations in convergence experience in the last two centuries. The starting point for this exercise is the set of various conjectures proposed in the historical literature which link that long-run convergence experience to conditions in international factor markets. The aim is to present a unified theoretical framework which captures the essence of the historical convergence record in a manner consistent with historical factor market experience.

This emphasis on factor convergence is not intended to dismiss the significance of other convergence mechanisms, most notably productivity convergence via technology transfer. However, the theoretical, empirical, and historical record suggests that the emphasis on technological catching-up has been at the expense of research on the impact of globalization in factor markets on convergence in a world of open economies. In the conclusion I weigh up these views as not competing, but rather

---

[16] 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 cores (cities) and peripheries (hinterlands).

[17] 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 $\delta(R)$ 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. This yields transitional dynamics for the frontier adjustment process.

complementary explanations of the sources of convergence; but for the present I use this abstract model to suggest how factor convergence may be an important part of the story.

3.1. Parable one: Capital mobility with distant frontier expansion—early-nineteenth century divergence

We begin, in chronological fashion, with initial conditions in world factor markets circa 1800. I will focus attention along the New World-Old World axis, the dimension along which most of the variation in convergence experience is played out, at least before 1914 (Williamson 1995). I argue that this era is best thought of as a time of quasi-mobile capital, with poorly mobile labor and resources.

With regard to the assumption of financial market integration, several authors have studied the process of long-run integration in world capital markets, and the stylized facts, such as they are, seem to suggest capital mobility as early as the seventeenth century, albeit imperfect. Stronger claims have been made which suggest that nineteenth century capital markets, particularly in the second half of the century, may well have been as integrated as world capital markets today (Edelstein 1982; Neal 1985; 1990; Obstfeld 1986; 1995; Zevin 1992).

However, we do need to be aware of the difference between financial capital flows and the flows of physical capital goods. Financial flows obtain whenever a country has a current account imbalance, by definition. Thus, merchandise trade imbalance on, say, consumer manufactures or food, will generate a saving-investment inequality, *ceteris paribus*. This is not the same as a flow of physical capital goods within the trade balance. However, the two may substitute. For example, if a frontier economy of the nineteenth century wishes to build infrastructure, such capital projects may be partly non-tradable in nature; labor may be diverted to that purpose domestically, but that will lead to a diminution of traded goods production; *ceteris paribus*, that will entail a trade deficit as long as long-run permanent consumption does not change. Thus, a foreign country may finance capital accumulation without actually providing the physical capital goods. But both mechanisms, by delinking saving and investment, create a simultaneous international flow of funds and a country-specific change in capital accumulation.

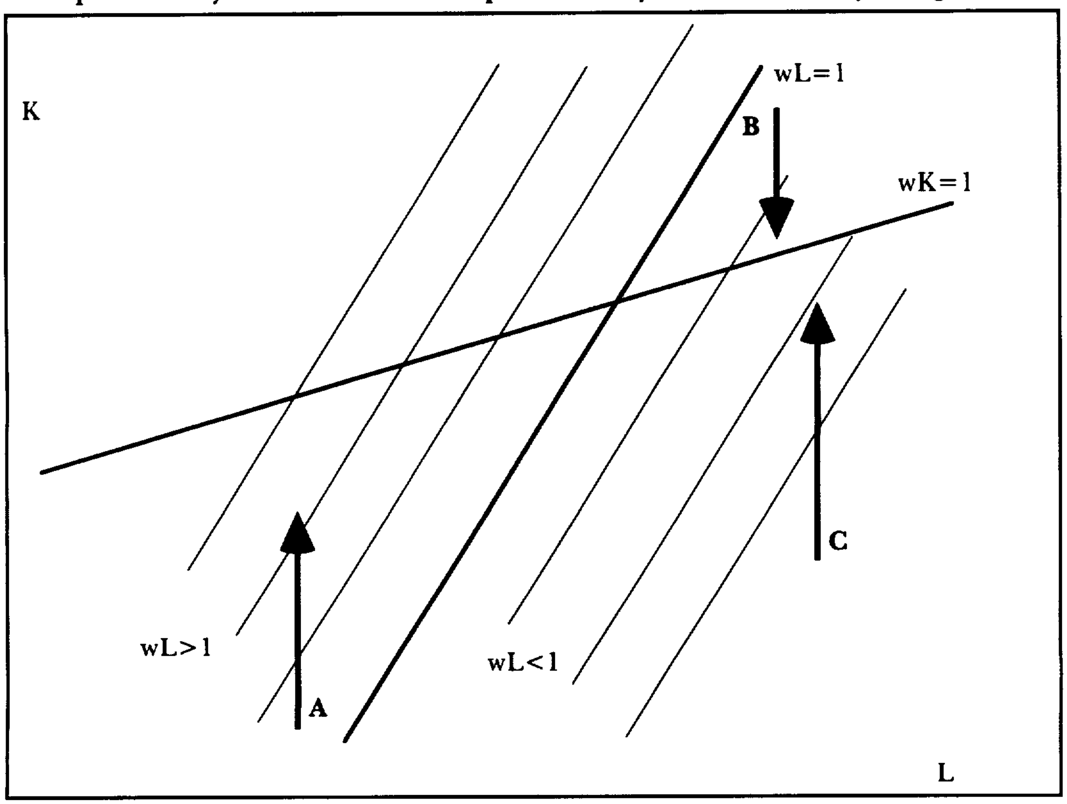
In practice, even physical capital goods could be considered quasi-mobile in the era: witness the increasing specialization of early industrializers, notably Britain, in manufactures in the early nineteenth century. Britain soon became a net exporter of manufactured goods, and a net importer of agricultural goods (foodstuffs), and some of her manufactured exports became the imported capital goods of overseas trading partners, including the New World economies. By this yardstick, many manufactured capital goods were becoming internationally traded throughout the nineteenth century: for example, textile machinery, railroad equipment, agricultural machinery.

With regard to labor mobility, in contrast, this era preceded the age of mass migration in the late nineteenth century; that surge in migration was released, in part, by the subsequent dramatic declines in passage costs as ships turned from sail to steam. For simplicity, then, we consider labor L poorly mobile in this period, and, in fact, keep L fixed as an abstraction.

With regard to potentially mobile natural resources we may note that intermediate products like oil, coal, and minerals were of limited importance in world trade in this era (compared to finished goods), in contrast to the subsequent rise in the trade of such intermediate inputs during and after the so-called Second Industrial Revolution, and particularly in the twentieth century. Such bulky resources were also hindered in their movement by high ocean freight shipping rates which declined only later in the nineteenth century (Harley 1988; North 1958). For simplicity, then, I also consider potentially tradable resources R as fixed for the moment.

This scenario just outlined is best simplified by studying the convergence implications in the basic model with international capital quasi-mobility (but fixed labor and resources) for a small open frontier economy, one abundant in resources (relative to the world) but having a relative scarcity of labor and capital. Figure 3a traces the dynamics of factor movement in this case, with attention restricted to (K,L)-space. Consider trajectory A for a New World economy initially characterized by dual scarcity of capital and labor ($w_L > 1$ and $w_K > 1$). K is internationally mobile, and, since $w_K > 1$ (the world price), capital inflow ensues, with a trajectory converging toward the steady state, an equilibrium with $w_K = 1$. Along this trajectory wage and labor productivity are characterized by divergence (initially relatively high and increasing). As noted earlier, the divergence property holds even if weak labor mobility is allowed, at least on the initial phase of the transitional dynamic.

Figure 3a
Capital mobility with distant frontier expansion—early-nineteenth century divergence



The divergence result, however, is consistent with the empirical evidence which suggests an emergence of significant wage and labor productivity gaps between the New and Old World in the early nineteenth century. The intuition behind the general story is as follows: when a remote frontier opens up to foreign exploitation, its abundant resources attract capital; such thinly-settled outposts experience rapid output growth, but if labor is poorly equipped to chase capital to these distant enclaves, then divergence must necessarily result; relative capital scarcity is offset by the foreign investment flows, but such flows only worsen the relative scarcity of labor, meaning even higher wages and labor productivities. The same international factor market conditions would tend to be associated with convergence in the Old World, either on trajectories B for labor-rich, capital-rich regions ($w_L < 1$ and $w_K < 1$; e.g., Britain and parts of Northern Europe), and on trajectories C for labor-rich, capital-scarce regions

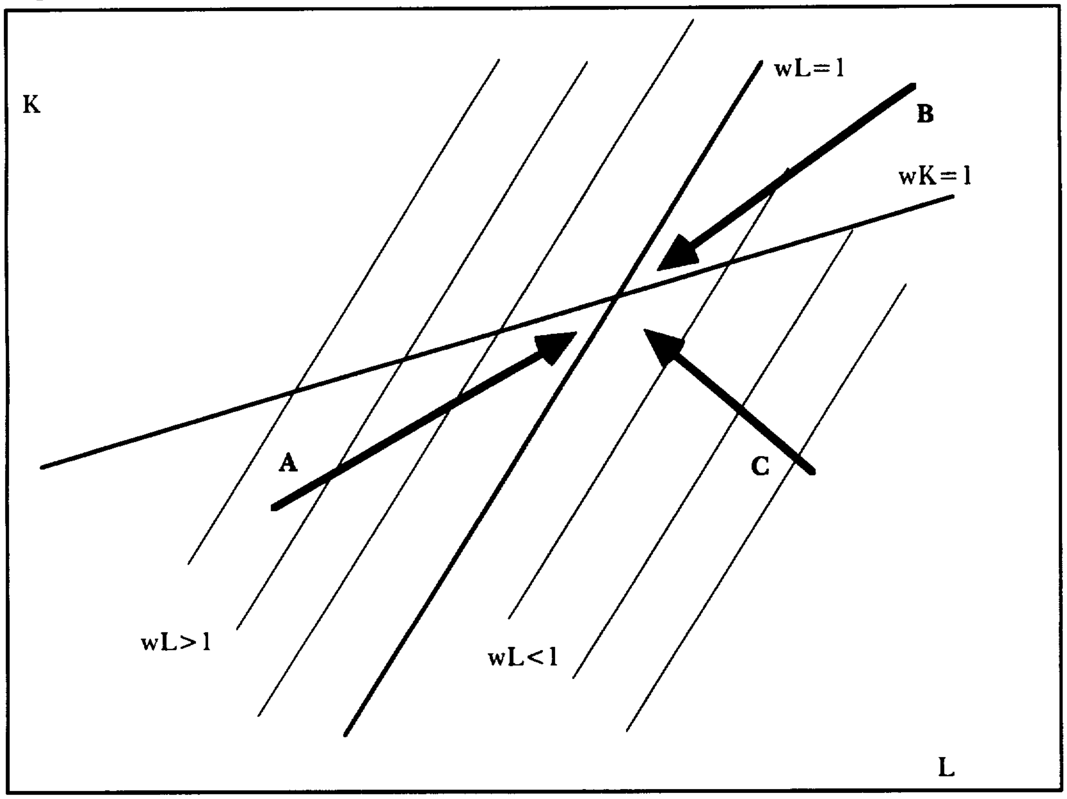
($w_L < 1$ and $w_K > 1$; e.g., newly industrializing and peripheral Europe). The rich regions in Europe export K and the poor regions import K, so for these two regions convergence dynamics result (as in conventional growth models), as is clear by consideration of the w_L dynamics on paths B and C. Interestingly, such predictions by the model mirror convergence experience prior to 1870, with the simultaneous episodes of divergence between the New and Old Worlds and convergence within the Old World (Williamson 1995).

3.2. Parable two: Capital and labor mobility in the age of mass migration—late-nineteenth century convergence

The emergence of massive labor migration in the late-nineteenth century represents a change in the dynamics of the model. As stressed by Jeffrey Williamson (1996), this increased labor mobility raised the possibility of convergence through migration, both within and between the New and Old Worlds. In the New World, labor chases abundant resources, being most attracted to the regions where labor scarcity and wages are highest; labor is most inclined to leave those areas of the Old World where labor scarcity and wages are lowest. Capital mobility may persist during this era, but now labor and capital jointly chase resources. Convergence properties now depend on the nature of the dual speeds of adjustment in the system, at least in the short run.

An illustration of the dynamics of this case is presented in Figure 3b. A typical New World country has an initial endowment characterized by labor and capital scarcity at A. However, factor inflows as in the model of Figure 2 now take place, and A's endowment shifts over time in such away that initial high wages and productivity decline, with w_L and w_K decreasing on the transition path. Different trends in w_L are seen in the Old World. A relatively capital-rich (core European) economy like B experiences factor outflows, with both w_L and w_K rising on the transition path. An intermediate case is that of a capital-scarce (peripheral European) economy like C, which experiences capital inflows but labor outflows, with w_L rising and w_K falling on the transition path. Inspection of the w_L trajectories for these three cases indicate that all three economies exhibit factor price convergence toward $w_K = w_L = 1$. In addition, w_L is an index of real wages and labor productivity, so there is a prediction of absolute convergence in these levels.

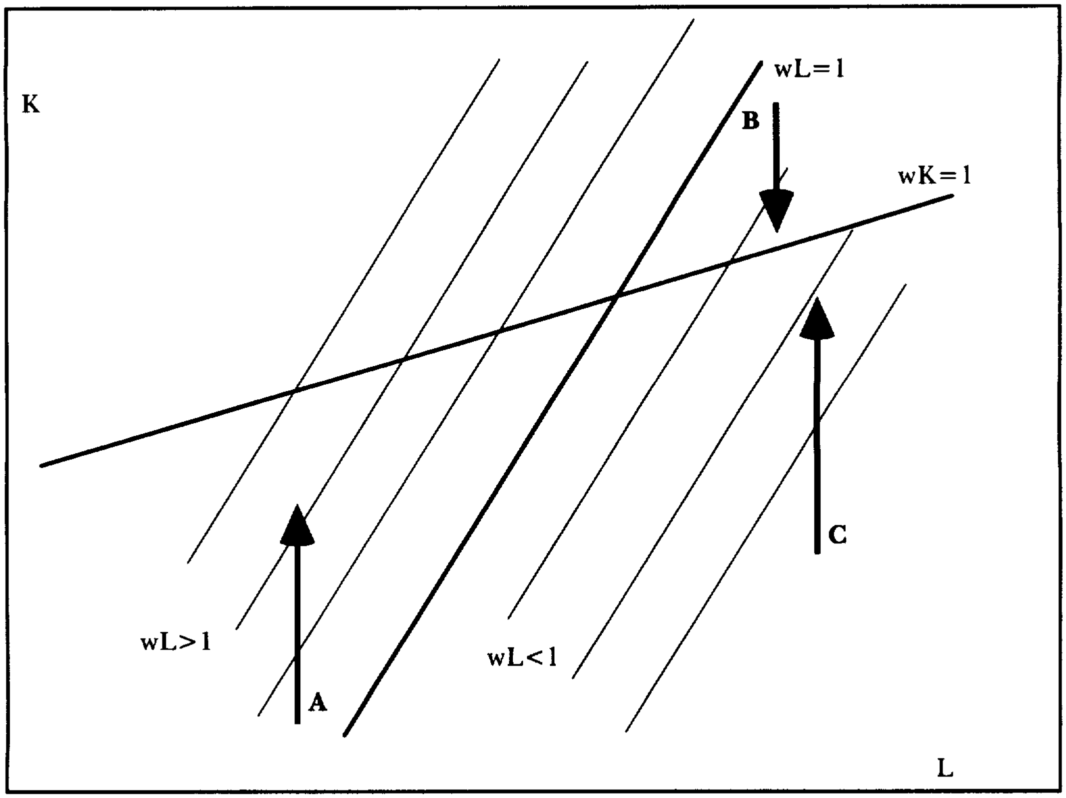
Figure 3b
Capital and labor mobility in the age of mass migration—late-nineteenth century convergence



3.3. Parable three: Capital mobility in a time of migration restrictions—interwar divergence

Given parables one and two, this case is easy to explain, and is depicted in Figure 3c. The end of mass migration after 1914 now effectively terminates the dynamics of parable two and implies a restoration of the conditions in the first parable. Convergence is retarded for the Old World regions because labor is no longer permitted the "safety valve" that was emigration to the new world. Instead, convergence within the Old World relies entirely on capital migration from abundant and into scarce regions (B to C). The convergence trend is modified for the New World regions, where growth is once again predicted based on resource abundance and persistent capital inflows in the absence of labor chasing. The dynamics replicate Figure 3a, an Old World-New World gap re-emerges.

Figure 3c
Capital mobility in a time of migration restrictions:—interwar divergence



Clearly, the results just presented may be sensitive to the factor mobility parameters. For example, if labor is barely mobile, then the New World path for A may be closer to vertically up, closer to Figure 3a, with at least short run divergence. This suggests a form of transition from phase 1 to phase 2. However, as long as labor is mobile in the long run, then eventually the transition paths will be forced to generate convergence. Of course, these findings parallel the increased speed of convergence seen from 1870 to 1913, and, as noted, simple calculations suggest a major impact of these factor flows on actual convergence (Taylor and Williamson 1997).[18]

---

[18] The major problem is that of the United States' "exceptionalism," its ability to maintain a productivity lead despite stronger pro-convergence pressures: the gap between the United States and Europe did not significantly narrow in this period (Abramovitz 1986). One possible explanation is the open frontier, a positive resource shock—one which gives way to another positive resource shock, the emerging resource base noted by Wright (1990), which will shortly be added to the present analysis.

It is obviously an oversimplification to suggest that conditions for international factor flow in the 1920s and 1930s somehow replicated those of the 1850s and 1860s. However, there is an ounce of truth here. Clearly, labor migration never again reached the volumes seen during the period 1870–1913. We may have a good sense of the power of mass migration to promote convergence when tolerated, and an equally good sense of the impact of migration restrictions on protecting real wages and living standards when these barriers were erected in the twentieth century. We know much less about the extent of capital market integration and its variation over time. The collapse of the classic gold standard was the principal symptom of the disintegration in the world capital market following World War One, but just how well-integrated had capital markets become between, say, 1870 and 1914? And how much of that integration was lost in the 1920s and 1930s?

The empirical basis for the present model will be examined in the next section, but such issues force us to reflect on what is missing from this description. We have no technology transfer in this model as in the classic catching-up model, we have no convergence via trade, and no human capital: everything rests on conventional factor accumulation. I will argue that this makes most sense for the nineteenth century (phases 1 and 2), but that other features warrant inclusion later. An obvious feature we *can* incorporate in this model is resources, following the ideas of Gavin Wright (1990). These ideas illustrate another force for early twentieth-century divergence, particularly the United States' exceptionalism in sustaining fast growth from a high productivity starting point (Abramovitz 1986).[19] In this framework, a sudden resource discovery in a New World economy like A in Figure 3c acts as a positive shock to total factor productivity when the resources are exploited and used in production: A moves even further away from equilibrium as both w_L and w_K temporarily increase in response to the increased endowment of resources. Since these resources are fixed and non-tradable, initially this resource advantage persists over time, and places the economy on an even more divergent path in the interwar period. Thus the Williamson and Wright stories overlap at this juncture: New World experience with resource booms

[19] Of course, the U.S. "resource shock" perpetuates U.S. exceptionalism in growth performance by dint of its appearance just at the time of the "closing of the frontier," the frontier having been one earlier source of U.S. exceptionalism, I have argued.

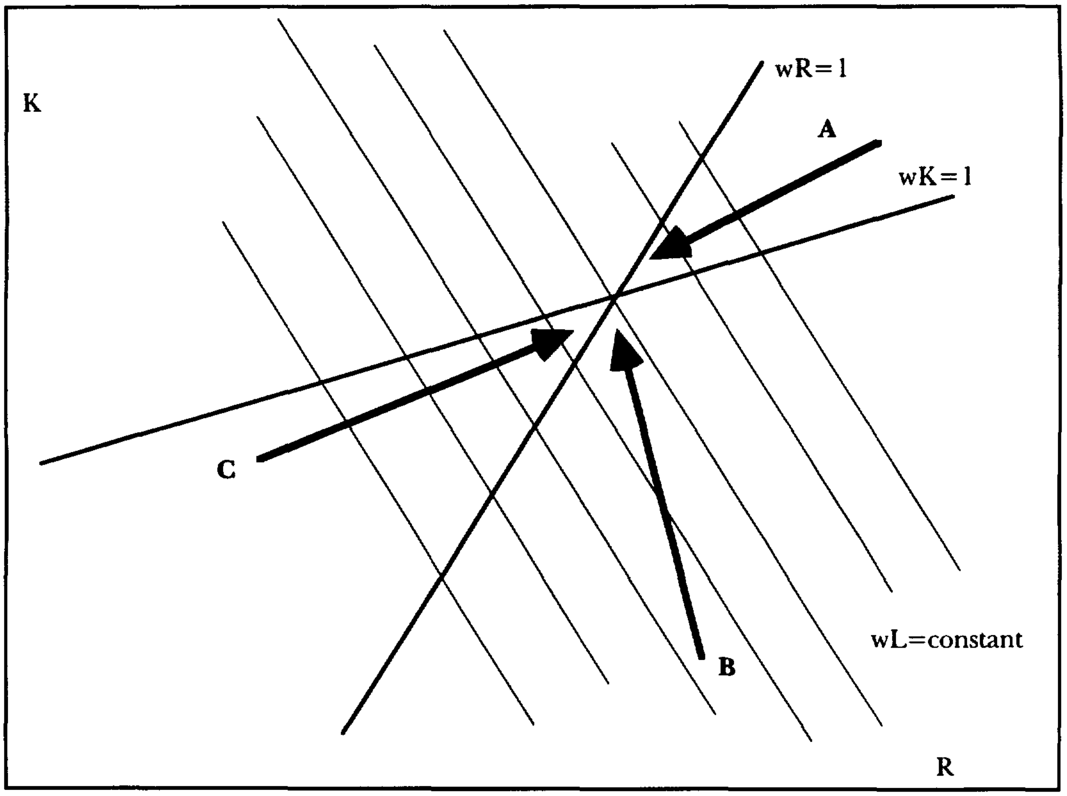
and immigration restrictions jointly enhanced productivity growth relative to resource-scarce and labor-abundant economies elsewhere. Such conditions would persist until they were changed, not by the resumption of labor mobility, but by the evolving mobility of the resources themselves in the late-twentieth century.

3.4. Parable four: Resource and capital mobility in the modern era—post-1945 convergence

Our model can be easily modified to encompass a new phase with labor (L) now immobile, capital (K) continuing to be mobile, and resources (R) beginning to be mobile. The dynamics of Figure 2 are now replaced by those of Figure 3d. Since K and R are now the mobile factors, they appear on the axes of the endowment space depicted in the graph. With this change, lines of constant wages and labor productivity are now sloped as shown (w_L = constant): to maintain a constant wage, declines in K must be offset by increases in R, and vice versa. Capital and resources trade internationally at world prices equal to one, and equilibrium obtains when $w_K = w_R = 1$. The standard factor mobility processes bring economies toward the steady state: capital inflows obtain when capital is scarce ($w_K > 1$), and resource inflows when resources are scarce ($w_R > 1$); similarly outflows occur when the mobile factors are relatively abundant ($w_K < 1$ or $w_R < 1$).

Just as we need a new model, we also need to relabel our typology of countries. In Figure 3d, country A is a rich country (w_L high), a capital-abundant country ($w_K < 1$), and a resource-abundant country ($w_R < 1$); for example, the United States in 1950 in Wright's framework. Country B is a middle-income economy (w_L in the middle) with capital scarce ($w_K > 1$), but resources even more scarce ($w_R >> 1$); for example, East Asian NIC economies in 1950. Country C is poor (w_L low), capital scarce ($w_K > 1$), but resource-abundant ($w_R < 1$); it might be a resource (primary product) exporter, like many LDCs in 1950.

Figure 3d
Resource and capital mobility in the modern era—post-1945 convergence



Note, however, that in the steady state, and along each trajectory, the lines w_L=constant may be different in each case (A, B and C) as a result of different endowments of the fixed factor F. The reason is that labor is immobile, and this prevents complete (ultimate) absolute convergence of wage and productivity levels. This is a general property of specific factor models when the number of factors exceeds the number of goods, and only in certain special cases can the mobility of a subset of factors yield complete factor price equalization (Dixit and Norman 1980, 122–25; Findlay 1995, 26–32).

Still, the model does predict conditional and partial convergence as follows. Consider the three trajectories A, B, and C. We see that convergence is predicted for all three regions in this regime, given the initial relative wages and labor productivities. A is initially high-income but has its resource and capital advantages eroded over time. B began as middle income and finds w_L increasing over time; B's resource scarcity problem is solved. C began as low income and grows as capital inflows compensate for resource outflows. However, to reiterate, this model is harder to interpret because it does admit possibly different steady states: C's long-run level of w_L may be different to that of B and depends on fixed factors (L and F).

4. THEORY VERSUS HISTORY? OR; WHAT USE IS THIS MODEL?

This paper has presented a simple view of long run convergence in the world economy where factor accumulation and factor mobility play a central role. The model is theoretically complete and is a formal development of ideas found in economic history literature, notably those of Williamson (1995) on labor and Wright (1990) on resources. Yet is such a view of convergence justified? The model is spare, and omits so many other possible growth and convergence mechanisms. These naturally warrant inclusion in any complete and universal growth model, but a review of the empirical shortcomings of the present model suggest that these omissions may be of second order in terms of quantitative significance.

First, we have excluded long-run factor accumulation with persistence. Yet this is not a major deficiency. Domestic agents have no factor accumulation process specified in the model, but that could easily be added. At the margin, international factor mobility would still determine allocation patterns when operational; migration, capital, or resource flows would always equate domestic and world factor prices in the mobile factors in the long run. This is not a fatal theoretical flaw. Nor is the second omission, an exclusion of long-run persistent growth. As Mankiw (1995) recently notes, whilst staunchly defending the simple factor-driven Solovian model, the true first test of growth theory is to explain the variations in economic performance across countries and over time; the tougher challenge of explaining the very long processes of technical change would seem to require a very different sort of theory (Mokyr 1992). Following Mankiw, we separate accumulation from technical change and focus on the former; it would be a simple addition to introduce a Solow-style exogenous rate of technical change into the model in the local and global economy. Ambitious growth theorists have certainly not shrunk from modeling endogenous technological change, incorporating models of research and development, product variety, and technology (Romer 1990; 1993; Grossman and Helpman 1991); but the empirical performance of these models remains disappointing, even for OECD economies with adequate data and a presumed well-behaved linkage between research inputs and technology outputs (Jones 1995a; 1995b).

A third omission is more serious, a formulation which denies any role for technological catching-up in low productivity countries. This mechanism stood at the center of the convergence literature since Abramovitz (1986) and Baumol (1986), and the idea dates back to the seminal ideas of Gerschenkron (1962) and Veblen (1915). Should this canonical insight be so casually discarded? To reiterate: probably not, although its inclusion and supposed validation are not without difficulty. Consider the post-1950 period, when data for a large cross section of countries is available to try to establish this force at work. Clearly, naive bivariate tests for (unconditional) β-convergence in output per capita or per worker (Baumol 1986) do not test for the convergence of productivity levels via catching up: they omit controls for capital deepening and other processes which might generate convergence. Addressing this deficiency, Dowrick and Nguyen's (1989) elegant and well-specified econometric model does far better, and find results consistent with a catching-up form of productivity convergence. Their regression analysis is not wedded to any particular model of factor accumulation. It includes growth rates on the left and, on the right, accumulation of factors plus an initial income per worker term (which has a significant negative coefficient). The latter term is often colloquially referred to as a "catch-up" term. This language, and the conclusions drawn from this result are problematic. Consider, in opposition, an equally careful piece of econometric work by Mankiw, Romer, and Weil. (1992) In contrast they seize the Solovian model (augmented to include human capital) as the null, and formally derive its implications. Moreover, their model assume constancy and exogeneity of technical change in all countries, excluding axiomatically the possibility of productivity convergence via catch-up. In this model, the steady-state and transitional dynamics towards it are central. Lower initial income implies greater distance from the country-specific steady-state and, thus, faster initial growth. The model's econometric analog regresses growth on factor accumulation and initial level of income per capita. This sounds familiar: it is exactly the same form of regression as Dowrick and Nguyen. The two models make directly conflicting assumptions about the possibility of technological catching-up *but imply identical regression equations*! The models are econometrically equivalent, and cannot be discriminated by any test, notwithstanding the fact that Dowrick and Nguyen had no controls for human capital and Mankiw, Romer, and Weil did. A positive coefficient in the first model implies productivity convergence, and in the second implies convergence via factor accumulation along the transition path. Thus, growth regressions of this type, so often replicated, provide no *prima facie* evidence for or against productivity convergence, and need careful interpretation.

An incisive recent contribution from Milbourne (1995) can save us from this econometric impasse: the Solovian process of factor convergence favored by Mankiw, Romer, and Weil can be joined with the Gerschenkronian process of productivity convergence emphasized by Dowrick and Nguyen—*and* we can test for the presence of each. The data requirements are more intensive, since measures of total factor productivity levels, as well as income levels, are needed. The results are not unfavorable to either camp: rates of convergence in overall income per capita may be about 2% per annum due to factor convergence and 2% per annum due to factor convergence. Thus, although nontrivial, technological convergence perhaps accounts for about half of the overall postwar convergence experience.

This balance of convergence forces does not merit the exclusion of the catch-up mechanism from the present model, but it would be simple to add. Indeed, if technology is seen as a factor, or even embodied in capital, it is even conceivable to model technology transfer just as we have modeled the mobility of other productive inputs in this paper. Furthermore, this finding is only for the postwar period and more research is warranted to discriminate between factor convergence and productivity convergence in other periods. For example, in a recent exercise for the late nineteenth century, controlling for land, labor, and capital accumulation, I found no evidence for a significant "catch-up" term (Taylor 1996d). Growth seemed to be almost entirely driven by factor endowments, that is, by how capital-labor and land-labor ratios evolved over time. Fitted growth with this model yielded almost exactly the same convergence patterns 1870–1913 as were actually seen. For that era, and for at least a select group of countries in the Greater Atlantic Economy, the factor convergence paradigm may be right one, and the productivity convergence paradigm may be less relevant, though more empirical research is needed on this interesting distinction between alternative but non-exclusionary growth mechanisms.

Of course the simple model omits other considerations. There is no mention of human capital accumulation. However, historical evidence supporting a role for human capital in late-nineteenth century growth is scant (O'Rourke and Williamson 1995; Taylor 1996d). And even results for the contemporary era cannot escape the general finding that in most growth regressions the only certain and robust findings relate to the impact of physical capital accumulation, usually measured via investment shares of GDP (Levine and Renelt 1992). Human capital impacts are less robust, and have less quantitative significance in explaining cross-sample variations in growth performance as between, say, slow-growth Latin America and fast-growth East Asia (Taylor 1996c).

This model also omits trade as a pro-convergence force. Of course, there is ample evidence to suggest that trade *indirectly* affects convergence since openness appears to be a determinant of factor accumulation, as would be expected in a small open economy where government intervention may distort domestic capital prices relative to world prices (De Long and Summers 1991; 1993; De Long 1992; Jones 1994; Taylor 1992; 1994a; 1994b; 1996c; 1995). Could trade *directly* affect convergence in per capita incomes?

There is certainly evidence that late-nineteenth century trade and commodity market integration caused factor price convergence (O'Rourke, Taylor and Williamson 1996), as in the standard models of international trade. There is evidence for the late-twentieth century too (Ben-David 1993; 1995). But do results on the *relative* convergence in factor prices imply similar conclusions regarding the impact of trade on the convergence of *absolute* levels of incomes per capita or real wages? Theory would suggest not, at least for output convergence measures: in any open-economy trade model, the impact of commodity-price changes on factor rewards is first order (consider the Stolper-Samuelson theorem), but the impact of the same changes on real output is second order (consider the counterfactual dead-weight loss if factors failed to reallocate across sectors, maintaining the old output mix at the new output prices). Empirical evidence for a late-nineteenth century sample of countries—a sample where trade-induced factor price convergence is seen—does indeed show that the impact of trade on output convergence is negligible (Taylor 1996d). Obviously more empirical work is needed, but theory presently discourages any emphasis on trade as a convergence mechanism, and with it any urge to complicate this present model with many traded goods, demand and supply and net trades of products, and considerations of the trade balance. Theory *does* presume a first-order impact of factor accumulation on output measures, supporting the assumptions of the present model.

Rather than focusing on what is missing, it is perhaps better to end on a discussion of what is included in the present model. Its predictions accord with convergence experience over the period since the mid-nineteenth century, and are based only on the conventional wisdom concerning international factor mobility in each period. The unprecedented mass migrations of the period 1870–1913 have never been seen at other times, due to costs (before the 1870s and 1880s) and policy (after the 1920s) and recent empirical research has made some advances to explain the mechanics of that mass migration process in economic terms (Hatton and Williamson 1994). Capital mobility in the world economy has generally been high throughout the period, but not without sporadic crises that put brakes on international investment (Eichengreen 1990). Further research is needed to establish better criteria for capital mobility in the world economy at various points in time, however (Obstfeld and Taylor 1997; Taylor 1996b; Taylor 1996a). Lastly, the inclusion of resource flows admits an important mechanism in the growth process, and captures flows of inputs which have now risen to great importance for certain countries (Wright 1990). There is even tentative evidence that relative resource abundance matters for growth, as in the recent findings of Sachs and Warner (1994; 1995); their conclusion that high net resource exports are associated with low growth rates may equivalently be read as saying that net resource *imports* have a positive impact on growth. This is the precise implication of the present model once resources are released to flow (to chase labor and capital), moving from the resource-rich countries to alleviate growth constraints in the resource-scarce, thus shifting relative resource-per-worker endowments.

If a model of long-run growth and convergence patterns since the nineteenth century is sought, a many factor model of economic growth is certainly required; at least four factors (land, labor, capital, resources) are needed; the international mobility of these factors needs to be confronted in all epochs; and the process of factor convergence seems to be an indispensable and robust ingredient. The present model offers a step in this direction.

REFERENCES

Abramovitz, M. 1986. Catching Up, Forging Ahead, and Falling Behind. *Journal of Economic History* 46 (June): 385–406.

Barro, R. J., N. G. Mankiw, and X. Sala-i-Martin. 1992. Capital Mobility in Neoclassical Models of Growth. *American Economic Review* 85 (March): 103–15.

Baumol, W. 1986. Productivity Growth, Convergence and Welfare: What the Long-Run Data Show. *American Economic Review* 76 (December): 1072–85.

Ben-David, D. 1993. Equalizing Exchange: Trade Liberalization and Income Convergence. *Quarterly Journal of Economics* 108 (August): 653–80.

Ben-David, D. 1995. Trade and Convergence Among Countries. University of Houston. Photocopy.

Cronon, W. 1991. *Nature's Metropolis: Chicago and The Great West.* New York: Norton.

De Long, J. B. 1992. Productivity Growth and Machinery Investment: A Long-Run Look. *Journal of Economic History* 52 (June): 307–24.

De Long, J. B., and L. H. Summers. 1991. Equipment Investment and Economic Growth. *Quarterly Journal of Economics* 106 (May): 445–502.

De Long, J. B., and L. H. Summers. 1993. How Strongly Do Developing Economies Benefit From Equipment Investment? *Journal of Monetary Economics* 32 : 395–415.

Dixit, A. K., and V. Norman. 1980. *Theory of International Trade.* Cambridge: Cambridge University Press.

Dowrick, S., and D.-T. Nguyen. 1989. OECD Comparative Economic Growth 1950–85: Catch-Up and Convergence. *American Economic Review* 79 (December): 1010–30.

Edelstein, M. 1982. *Overseas Investment in the Age of High Imperialism.* New York: Columbia University Press.

Eichengreen, B. J. 1990. Trends and Cycles in Foreign Lending. In *Capital Flows in the World Economy,* edited by H. Siebert. Tübingen: Mohr.

Findlay, R. 1995. *Factor Proportions, Trade, and Growth.* Cambridge, Mass.: MIT Press.

Gerschenkron, A. 1962. *Economic Backwardness in Historical Perspective.* Cambridge, Mass.: Harvard University Press.

Grossman, G. M., and E. Helpman. 1991. *Innovation and Growth in the Global Economy.* Cambridge, Mass.: MIT Press.

Harley, C. K. 1988. Ocean Freight Rates and Productivity, 1740–1913: The Primacy of Mechanical Invention Reaffirmed. *Journal of Economic History* 48 : 851–876.

Hatton, T. J., and J. G. Williamson. 1994. *Migration and the International Labor Market, 1850–1939.* London: Routledge.

Jones, C. I. 1994. Economic Growth and the Relative Price of Capital. *Journal of Monetary Economics* 34 : 359–82.

Jones, C. I. 1995a. R&D-Based Models of Economic Growth. *Journal of Political Economy* 103 : 759–84.

Jones, C. I. 1995b. Time Series Tests of Endogenous Growth Models. *Quarterly Journal of Economics* 110 : 567–85.

Kim, S. 1995. Regions, Resources, and Economic Geography: The Evolution of U.S. Regional Economies, 1860–1987. Washington University in St. Louis (September). Photocopy.

Levine, R., and D. Renelt. 1992. A Sensitivity Analysis of Cross-Country Growth Regressions. *American Economic Review* 82 (September): 942–63.
Maddison, A. 1991. *Dynamic Forces in Capitalist Development: A Long-Run Comparative View.* Oxford: Oxford University Press.
Mankiw, N. G. 1995. The Growth of Nations. *Brookings Papers on Economic Activity* 1 : 275–310.
Mankiw, N. G., D. Romer, and D. N. Weil. 1992. A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics* 107 (May): 407–37.
Milbourne, R. 1995. Factor Convergence Versus Productivity Convergence. University of New South Wales. Photocopy.
Mokyr, J. 1992. *The Lever of Riches.* Oxford: Oxford University Press.
Mussa, M. 1978. Dynamic Adjustment in the Heckscher-Ohlin-Samuelson Model. *Journal of Political Economy* 86 : 775–791.
Neal, L. 1985. Integration of International Capital Markets: Quantitative Evidence from the Eighteenth to Twentieth Centuries. *Journal of Economic History* 50 (June): 219–26.
Neal, L. 1990. *The Rise of Financial Capitalism: International Capital Markets in the Age of Reason.* Cambridge: Cambridge University Press.
Nelson, R. R., and G. Wright. 1992. The Rise and Fall of American Technological Leadership. *Journal of Economic Literature* 30 (December): 1931–64.
North, D. C. 1958. Ocean Freight Rates and Economic Development, 1750–1913. *Journal of Economic History* 18 : 537–555.
O'Rourke, K. H., A. M. Taylor, and J. G. Williamson. 1996. Factor Price Convergence in the Late Nineteenth Century. *International Economic Review* 37 (August): 499–530.
O'Rourke, K. H., and J. G. Williamson. 1995. Open Economy Forces and Late 19th Century Scandinavian Catch-Up. Working Paper Series no. 5112, National Bureau of Economic Research (May).
Obstfeld, M. 1986. Capital Mobility in the World Economy: Theory and Measurement. *Carnegie-Rochester Conference Series on Public Policy* 24 .
Obstfeld, M. 1995. International Capital Mobility in the 1990s. In *Understanding Interdependence: The Macroeconomics of the Open Economy*, edited by P. B. Kenen. Princeton, N.J.: Princeton University Press.
Obstfeld, M., and A. M. Taylor. 1997. The Great Depression as a Watershed: International Capital Mobility in the Long Run. In *The Great Depression and the American Economy in the Twentieth Century*, edited by M. D. Bordo, C. D. Goldin and E. N. White. Chicago: University of Chicago Press. Forthcoming.
Romer, P. M. 1990. Endogenous Technological Change. *Journal of Political Economy* 98 (October): S71–102.
Romer, P. M. 1993. Idea Gaps and Object Gaps in Economic Development. *Journal of Monetary Economics* 32 (December): 543–73.
Sachs, J. D., and A. M. Warner. 1994. Natural Resources and Economic Growth. Harvard University (August).
Sachs, J. D., and A. M. Warner. 1995. Economic Convergence and Economic Policies. Working Paper Series no. 5039, National Bureau of Economic Research (February).
Slaughter, M. J. 1995. The Antebellum Transportation Revolution and Factor-Price Convergence. Working Paper Series no. 5303, National Bureau of Economic Research (October).

Solow, R. M. 1956. A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics* 70 (February): 65–94.
Swan, T. W. 1956. Economic Growth and Capital Accumulation. *Economic Record* 32 (November): 334–61.
Taylor, A. M. 1992. Argentine Economic Growth in Comparative Perspective. Ph. D. dissertation, Harvard University.
Taylor, A. M. 1994a. Three Phases of Argentine Economic Growth. Working Paper Series on Historical Factors in Long Run Growth no. 60, National Bureau of Economic Research (October).
Taylor, A. M. 1994b. Tres fases del crecimiento económico argentino. *Revista de Historia Económica* 12 (Fall): 649–83.
Taylor, A. M. 1995. Growth and Convergence in the Asia-Pacific Region: On the Role of Openness, Trade and Migration. Working Paper Series no. 5276, National Bureau of Economic Research (September).
Taylor, A. M. 1996a. International Capital Mobility in History: Purchasing Power Parity in the Long-Run. Working Paper Series no. 5742, National Bureau of Economic Research (September).
Taylor, A. M. 1996b. International Capital Mobility in History: The Saving-Investment Relationship. Working Paper Series no. 5743, National Bureau of Economic Research (September).
Taylor, A. M. 1996c. On the Costs of Inward-Looking Development: Price Distortions, Growth, and Divergence in Latin America. Working Paper Series no. 5432, National Bureau of Economic Research (January).
Taylor, A. M. 1996d. Sources of Convergence in the Late Nineteenth Century. Working Paper Series National Bureau of Economic Research. Forthcoming.
Taylor, A. M., and J. G. Williamson. 1997. Convergence in the Age of Mass Migration. *European Review of Economic History* . Forthcoming.
Veblen, T. 1915. *Imperial Germany and the Industrial Revolution.* New York: Macmillan.
Williamson, J. G. 1995. The Evolution of Global Labor Markets since 1830: Background Evidence and Hypotheses. *Explorations in Economic History* 32 (April): 141–96.
Williamson, J. G. 1996. Globalization, Convergence, and History. *Journal of Economic History* 56 (June): 277–306.
Wright, G. 1990. The Origins of American Industrial Success, 1879–1940. *American Economic Review* 80 (September): 651–68.
Zevin, R. B. 1992. Are World Financial Markets More Open? If So, Why and With What Effects? In *Financial Openness and National Autonomy: Opportunities and Constraints*, edited by T. Banuri and J. B. Schor. Oxford: Clarendon Press.