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ABSTRACT

Winners and Losers in a North-South Model of Growth, Innovation and Product Cycles*

The Paper examines the welfare gains from North-South trade and their distribution. We construct an endogenous growth North-South model with four Southern stages of development as possible equilibria: specialization in a traditional good; the South in addition copies Northern high-tech manufactured goods; the South begins to innovate in its own right and finally a stage in which the South only innovates, as in the North. We use this model to show that dynamic gains from trade and from Southern development through the stages can create new winners, unskilled workers in the North and possibly skilled workers in the South.

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NON-TECHNICAL SUMMARY

Historically trade between the developing countries (the 'South') and developed countries (the 'North') has consisted of exports of primary products and labour-intensive manufactures from the South, and exports of capital-intensive manufactures from the North. A new pattern of trade has been observed more recently. New innovative goods are first developed and produced in the North and exported to other countries, North or South. Then the famous Vernon 'product cycles' emerge: the South develops the ability to imitate many Northern activities (possibly, but not necessarily, with the intermediation of transnational companies) and production shifts to that region where they enjoy a competitive advantage.

An indication of how far we have come from the historical colonial division of labour is provided by data for trade in 'new products' (goods such as office machines, data-processing equipment, telecommunication equipment and semiconductors). Developing countries are increasingly specializing in exports of these new products: for some countries, Singapore and Malaysia in particular, that comprise over half their manufactured exports. These trends are consistent with Vernon-style product cycles in which the South imitates the North but does not innovate. They are also consistent with the South becoming a region of innovative activity possibly existing alongside imitation. There are certainly indications that parts of the South are becoming major innovators: in the ranking of patents granted in 1992: Taiwan is ranked first and South Korea tenth (World Competitiveness Report, 1995).

In the light of these stylized facts this Paper constructs a North-South 'new growth, new trade' model with changing patterns of trade in which the South can progress through a number of stages of development. The model has a two-factor, two-good Heckscher-Ohlin (HO) structure in both regions: the factors are skilled and unskilled labour, one high-technology sector produces an expanding variety of differentiated goods and the second is a 'traditional' low-technology sector. In the static HO framework, the relatively scarce factors of production in each bloc, unskilled labour in the North and skilled labour in the South, lose out from free trade. We revisit this winners and losers issue in a set-up where there are dynamics, as well as the traditional static, reallocative gains from trade. We also examine the effect of increased copying of new goods by the South (i.e. weaker patent protection) on world growth.

The defining feature of North-South models is asymmetry between the regions. In our model there are three ways in which the South differs from the North. First it is less efficient at adopting the technology available on a world-wide level. Second the speed with which the South learns from the North is less than that in the opposite direction. Third its endowment of skilled labour is

less than that in the North. We show how these three asymmetries, together with the degree of patent protection enjoyed by Northern firms (all exogenous in our model), give rise to four stages of development in the South as possible equilibria: specialization in the traditional sector (stage I); a stage II where the South in addition copies Northern innovative goods-producing 'product cycles'; a stage III where the South begins to innovate in its own right and finally a stage IV in which the South, like the North, only innovates.

The new (endogenous) growth aspect of the model highlights the dynamic aspects of these traditional trade issues. Whereas in a static HO framework the winners are skilled workers in the North and unskilled workers in the South, in our framework the dynamic gains from trade create additional winners: unskilled workers in the North. If the international diffusion of knowledge capital from North to South is sufficiently rapid then our results suggest the possibility that the remaining group, skilled workers in the South, could also become beneficiaries from trade.

In our model and others of this genre, knowledge capital is a public good. It follows that the level of private investment in R&D that adds to the stock of knowledge capital and drives growth is socially sub-optimal. There is therefore a role for governments to provide public support for R&D. However our research shows that the effects of such support depend crucially on which stage of development the South is in itself. More precisely, because the South is not homogeneous, the practical issue is which stage the particular Southern country under consideration finds itself. For example, if it is the stage in which imitation exists alongside innovation, then subsidies should be directed at supporting Southern innovation. In the same vein support for Northern innovation can be counterproductive because it simply encourages Southern imitation, which is a wasteful activity if innovation is possible in that region. However in the stage when the South specializes in the traditional good, no such problem occurs and support for Northern innovation is growth- and welfare-enhancing for the world.

Patent protection needs to balance two potentially conflicting objectives: encouraging innovation in the North and facilitating development in the South. Whether these do in fact conflict depends on the Southern stage of development. At a low level of development more stringent patent protection enforces traditional activity in the South by preventing copying. On the other hand in the stage where innovation and imitation coexist it will encourage innovation at the expense of imitation and thus increase world growth. Similarly and more surprisingly Northern aid aimed at increasing human capital in the South can have an ambiguous effect on world growth. In stages I and II it encourages copying, discourages Northern innovation and slows down growth. However throughout we have treated the diffusion rate as exogenous whereas one would expect it to be positively related to Southern

human capital. If this were the case then increasing the proportion of skilled workers in the South would also increase the North-South speed of knowledge transfer and see the progression into the imitation-innovation stage and finally the innovation stage, with positive effects on world growth. The one unambiguous benefit to both North and South arises from an increase in Southern efficiency across all sectors. Aid aimed at improving Southern infrastructure runs into none of the complexities arising from stronger patent protection or training the Southern workforce.

Our research establishes two mechanisms by which openness may increase world growth and welfare for both the North and South. The first is through specialization in which trade sees the North devoting more resources to innovative R&D. The second is through knowledge spillovers, which enable the South to progress into higher stages of development. However this second channel has an ambiguous effect on world growth. In stage II where the South only copies, increased spillovers reduce the incentive to innovate in the North and long-term world growth falls; but as spillovers increase further the South enters stages where it begins to innovate and world growth increases. Despite this negative effect of a transition from phase I to phase II, all our trade equilibria yield higher growth rates and welfare than the autarky regime even when the South is in its copying stage of development. Thus we have provided theoretical underpinnings that provide support for policies aimed at increased economic integration of the world economy, especially if this is accompanied by the strengthening of International Property Rights which have the effect of encouraging innovation and discouraging copying in the South.

1 Introduction

Historically trade between the developing countries (the 'South') and developed countries (the 'North') has consisted of exports of primary products and labour-intensive manufactures from the South, and exports of capital-intensive manufactures from the North. A new pattern of trade has been observed more recently. New innovative goods are first developed and produced in the North and exported to other countries, North or South. Then the famous 'product cycles' of Vernon (1966) emerge: the South develops the ability to imitate many Northern activities (possibly, but not necessarily, with the intermediation of transnational companies) and production shifts to that region where they enjoy a competitive advantage.

An indication of how far we have come from the historical colonial division of labour is provided by figures for trade in 'new products'. Table 1 shows the share of new products, defined to be goods such as office machines, data-processing equipment, telecommunication equipment and semiconductors, in manufactured exports for selected North-South economies. Developing countries are increasingly specialising in exports of these new products: for some countries—Singapore and Malaysia in particular—they comprise over half their manufactured exports. These trends are consistent with Vernon-style product cycles in which the South imitates the North but does not innovate. They are also consistent with the South becoming a region of innovative activity possibly existing alongside imitation. There are certainly indications that parts of the South are becoming major innovators: in the ranking of patents granted in 1992 Taiwan is ranked first and South Korea tenth (World Competitiveness Report, 1995).[1]

In the light of these stylized facts we set out to construct a North-South 'new growth, new trade' model with *changing* patterns of trade in which the South can progress through a number of stages of development. Theoretical research on such models was initiated by Krugman (1979) and progressed as a result of a number of authors including Grossman and Helpman (1990a, 1991a,b,c), Segerstrom (1991), Helpman (1993) and van Elkan (1996). Our model draws mainly upon Grossman and Helpman (1991b, in particular chapters 7 and 11, henceforth GH), and develops it in a number of important directions to incorporate *stages of Southern development*.[2]

[1] See Chui *et al.* (1998) for further discussion.

[2] In GH permanent exogenous differences between countries are assumed that result in either imitation of innovation, but not both. Segerstrom (1991) and van Elkan (1996) develop models in which firms can engage in these activities simultaneously. The paper by van Elkan is closest to ours in that she models two interacting economies developing between stages of imitation and then innovation. Endogenous growth in her model is driven by human capital accumulation determined

Table 1: Share of New Products in Manufactured Exports, 1980–1993.

	1980	**1985**	**1990**	**1993**
Developing economies	13.7	12.6	18.3	22.9
Asian NICS	16.2	17.5	28.0	31.7
Hong Kong	13.2	14.3	17.4	19.3
South Korea	10.8	13.3	23.7	24.4
Singapore	32.6	36.0	51.2	55.7
Taiwan	15.5	15.6	22.7	25.3
Malaysia	47.5	53.0	51.7	53.9
Thailand	0.7	2.2	24.2	24.7
Developed economies	7.6	11.2	11.3	12.6
United States	11.4	16.5	16.5	16.5
Japan	14.6	21.7	24.4	24.5

Source: World Economic and Social Survey, (1995).

We introduce a second factor of production, skilled labour, and alongside a high-technology sector producing an expanding variety of differentiated goods, we include a 'traditional' low-technology sector in both regions.[3] Considering the output of the high-technology sector as one good, these changes give the model a two-factor, two-good Heckscher-Ohlin (HO) structure suitable for assessing who benefits from free trade. In the static HO framework, the scarcer factors of production in each bloc, unskilled labour in the North and skilled labour in the South, lose out from free trade. We revisit this winners and losers issue in a set-up where there are dynamic, as well as the traditional static, reallocative gains from trade. Our more general model also enables us to examine the robustness of an important and apparently counterintuitive result in GH: in their one-factor, one-good, increased copying of new goods by the South (ie weaker patent protection) actually encourages Northern innovation and hence increases world growth.

The defining feature of North-South models are asymmetries between the regions.

by the intertemporal life-cycle optimization of households. This contrasts with the GH framework adopted in our paper where growth is Schumpeterian in character driven by R&D investment into new goods which enjoy monopolistic profits.

[3]A previous paper involving the authors, Currie *et al.* (1996), develops a more primitive model of stages of development close to GH with only one factor of production and no traditional sector.

In our model there are three ways in which the South differs from the North. First it is less efficient at adopting the technology available on a world-wide level. Second the speed with which the South learns from the North is less than that in the opposite direction. Third its endowment of skilled labour is less than that in the North. We show how these three asymmetries, together with the degree of patent protection enjoyed by Northern firms (all exogenous in our model), give rise to four stages of development in the South as possible equilibria: specialisation in the traditional sector (stage I); a stage II where the South in addition copies Northern innovative goods producing 'product cycles'; a stage III where the South begins to innovate in its own right and finally a stage IV in which the South, like the North, only innovates.[4]

The rest of the paper is organised as follows. Section 2 sets out the North-South trade model with the features described above. The steady state of the full model does not yield a simple closed-form solution. This leaves us two possible ways of proceeding. First we can limit the range of equilibria to be studied by imposing some restrictions on the exogenous parameters. Second we can study the equilibrium properties of the unrestricted model using numerical simulations. We adopt the first of these strategies in section 3 and go down the second route of numerical simulation in section 4. Section 3 also presents three intermediate analytical results for the steady state of the full model without characterising the complete equilibrium. These results apply to the full model when traditional activity exists in both regions. Then a necessary condition for any copying to exist in the South is that either the North-to-South knowledge spillovers are not instantaneous, or the pattern of Southern inefficiencies across sectors are such that comparative advantage in the South does not result in only innovation or specialization in the traditional activity. Our other analytical results characterise the full equilibrium for a special case where only skilled labour is used in the R&D sector, and only unskilled labour in the traditional sector. Then we can reproduce the GH result that in stage II weaker protection of Northern patents and increased Southern copying has the effect of *increasing* the innovation rate in the North and hence increasing world growth as well.[5] In stage IV, with this same restrictive assumption on the R&D

[4] A study that takes a more long-term view of development is to be found in Balwin et al (1998). Their 'stages-of-growth' model formalizes post-Industrial Revolution stages of industrialization in the North driven by the fall in the transactions cost of trade. Their final Southern stage of industrialization and possible convergence broadly corresponds to what is happening in our paper, though the modelling details are very different.

[5] This result is the focus of papers by Helpman (1993) and Lai (1998).

sector, we show that an increase in the speed with which the South learns from the North increases the Southern share of high-technology manufactured goods, and also increases world growth.

Section 4 uses numerical calculations of the full model to characterise the four equilibria, to investigate the robustness of the higher copying, higher growth relationship, and to assess the welfare effects on skilled and unskilled workers of North-South trade. The section concludes by relating the predictions of our model to the empirical literature on the effects of openness on growth. Section 5 summarises the results and discusses some of the policy implications.

2 The Model

In each bloc of a two-bloc world, North (N) and South (S), there are three sectors: a high-technology manufacturing sector, m, produces an expanding variety of differentiated goods; a traditional sector, z, produces a single traded homogeneous good; an R&D sector, r, produces blueprints for new or copied manufactured goods. All sectors use two factor inputs consisting of exogenously fixed skilled labour $\bar{H}^b$, and unskilled labour $\bar{L}^b$, $b = N, S$ in the aggregate. We assume equal populations in each region and normalise these to unity (ie $\bar{N}^N = \bar{N}^S = 1$), so that $\bar{H}^b$ and $\bar{L}^b$ become proportions. There is no labour mobility between regions. The ranking of unskilled-skilled labour intensiveness is: traditional, manufacturing and R&D. The assumed market structures for outputs are competitive for the traditional and R&D sectors and monopolistic for manufacturing. Labour markets are assumed to clear.[6]

Consumers consist of two representative households. Type l, $l = L, H$, supplies fixed quantities of labour to the labour market and maximises an intertemporal utility function,

$$U_l^b(t) = \int_0^\infty e^{-\rho(\tau - t)} \left\{ \frac{[(D_l^b)^\theta (Z_l^b)^{1-\theta}]^{1-1/\sigma} - 1}{1 - 1/\sigma} \right\} d\tau; \quad \theta \in [0,1], \sigma \neq 1; \qquad (1)$$

where ρ is the subjective discount rate, $\sigma < 1$ is the intertemporal elasticity of substitution, Z_l is the traditional good; and D_l^b takes the form

$$D_l^b = \left[\int_0^n (x_{lj}^b)^\alpha dj \right]^{1/\alpha}; \qquad \alpha \in (0,1) \qquad (2)$$

[6] A longer discussion paper by the authors, Chui *et al.* (1998), also examines the case in which, following Wood (1994), the Northern labour market fails to clear as a result of a floor on the unskilled/skilled wage ratio.

due to Dixit-Stiglitz, where n is the total number of varieties available, α is a taste parameter and x^b_{lj} is consumption of variety j by type l in bloc b.[7]

The consumers' optimization problem consists of two stages. Let p_j be the price of variety j and p_z be the price of the traditional good. Then the first stage is the current period maximisation of $(D^b_l)^\theta (Z^b_l)^{1-\theta}$ over the varieties given total household expenditure for each group of workers, $E^b_l = \int_0^n [p^b_j x^b_{lj}] dj + p_z Z^b_l$. This is a standard problem which yields demands

$$Z^b_l = (1-\theta)\frac{E^b_l}{p_z}; \qquad x^b_{lj} = \frac{\theta E^b_l p_j^{-\varepsilon}}{\int_0^n p_{j'}^{1-\varepsilon} dj'}; \qquad l = L,\, H, \tag{3}$$

where $\varepsilon = 1/(1-\alpha) > 1$ is the elasticity of substitution. At the maximum, $(D^b_l)^\theta (Z^b_l)^{1-\theta} = E^b_l / P$ where P is the price index for total consumption:

$$P = \left[\int_0^n p_j^{1-\varepsilon} dj\right]^{\theta/(1-\varepsilon)} p_z^{1-\theta}. \tag{4}$$

Hence the total demand for the variety j and for the traditional good Z are

$$x_j = \sum_{b=N,S} (x^b_{Lj} + x^b_{Hj}) = \frac{\theta E p_j^{-\varepsilon}}{\int_0^n p_{j'}^{1-\varepsilon} dj'}; \qquad Z = \sum_{b=N,S} (Z^b_L + Z^b_H) = \frac{(1-\theta)E}{p_z}, \tag{5}$$

where $E = \sum_{b=N,S} (E^b_L + E^b_H) = E^N + E^S$ is total world households' expenditure.

The second stage of the consumers' problem is intertemporal. Wealth W^b_l of type l consists of an equity stake in firms whose behaviour is set out below. Arbitrage in capital markets within each bloc ensures equality on the yield from these shares and that on a riskless loan, r^b. This implies budget constraints for the two types:

$$\dot{W}^b_L = r^b W^b_L + w^b_L \bar{L}^b - E^b_L; \quad \dot{W}^b_H = r^b W^b_H + w^b_H \bar{H}^b - E^b_H. \tag{6}$$

where $\mathbf{w}^b = [w^b_L, w^b_H]$ are the wage rates. Maximising (1) subject to (2), (3) and (6) and aggregating over both types of labour gives another standard result:

$$\dot{E}^b/E^b - \dot{P}/P = \sigma(r^b - \dot{P}/P - \rho), \tag{7}$$

[7] This assumption that all consumers in both blocs have the same tastes appears to be innocuous, although subject to the standard criticism that there is no such thing as a representative consumer. However Diwan and Rodrik (1991) develop a model in which protection of intellectual property rights (IPR) by the South is crucial precisely because it has a different set of preferences from the North. If IPRs are easily violated there will be little incentive, for example, for Northern pharmaceutical firms to research into cures for tropical diseases, which benefit the South, as opposed to cancer drugs, which mainly benefit the North.

where the budget constraint for aggregate wealth, $W^b = W_L^b + W_H^b$, is,

$$\dot{W}^b = r^b W^b + w_L^b \bar{L}^b + w_H^b \bar{H}^b - E^b, \tag{8}$$

and this completes the demand side of the model.

Turning to the supply side, since the traditional sector is perfectly competitive, the price is equal to the marginal cost. If both regions produce the traditional good, global price equalization then gives the following equality

$$p_z = C_z^N(\mathbf{w}^N) = C_z^S(\mathbf{w}^S). \tag{9}$$

In (9), unit cost functions $C_z^b(\mathbf{w}^b), b = N, S$, for the traditional sector and the unit factor requirements, $a_{Lz}^b(\mathbf{w})$ and $a_{Hz}^b(\mathbf{w})$ are given in Appendix A, equation (A.16), and are derived from the following, Cobb-Douglas production function

$$Z^b = A_z^b L_z^{1-\gamma_z} H_z^{\gamma_z} \tag{10}$$

where A_z^b is a productivity coefficient. Similarly, production in the manufacturing sector producing each variety is: $x^b = A_m^b L_m^{1-\gamma_m} H_m^{\gamma_m}$.[8] Let K^b be the knowledge capital defined below. The rate of production of new goods invented or copied in the R&D sector is:

$$\dot{n}_r^b = A_r^b K^b L_r^{1-\gamma_r} H_r^{\gamma_r}. \tag{11}$$

The cost functions $C_m^b(\mathbf{w}^b)$ and $C_r^b(\mathbf{w}^b)$ are defined analogously to $C_z^b(\mathbf{w}^b)$. Since we assume decreasing unskilled-skilled labour intensiveness across these sectors we put $\gamma_z < \gamma_m < \gamma_r$. Note that although K^N and K^S differ from one another, we assume that all researchers in the same region have access to a common body of knowledge.

We assume that the South is inefficient relative to the North in all sectors. If this inefficiency in uniform across sectors, with our constant returns to scale production functions this can be interpreted the quality of both skilled and unskilled labour in the North being uniformly higher than in the South (in addition to the proportion of skilled workers being higher). Alternatively (or in addition) the inefficiency could

[8] Acemoglu and Zilibotti (1999) investigate a model where manufacturers choose between the two types of labour and buy machines which complement either type. In addition labour productivity is different for each variety. When there is insufficient protection of property rights, the North will be encouraged mainly to develop machines which complement skilled workers, which results in a productivity gap in the South over a certain range of products. Their work only covers imitation in the South, but could be extended in principle to allow both imitation and innovation along the lines presented here.

be caused by poorer infrastructure in the South in which case it need not be uniform across sectors. To capture these ideas, we put

$$A_j^N = A_j^S \beta_j; \quad j = z, m, r; \quad \beta_j \geq 1. \tag{12}$$

There are no incentives within this set-up for the North to copy.[9] But in the South research activity referred to by subscript r can take two forms: innovation ($r = i$) and copying ($r = c$), with the latter being less costly than the former. We represent this as

$$A_i^S = A_c^S a_c; \quad a_c \leq 1. \tag{13}$$

In the South the R&D sector may be absent altogether in which case the region specialises in the traditional good and a stagnant range of old manufactured varieties. Then since the demand for each variety declines as the number of world varieties increases (see (5)), in the steady state the manufacturing sector disappears altogether. If the R&D sector does exist in the South then it can engage in imitation, resulting in product cycles of goods originating in the North but eventually being produced in the South. The South can also combine imitation and innovation in which case some new varieties are invented there. Finally the South may only innovate in its R&D sector. This gives us four stages of development for the South: specialisation in the traditional good and a fixed number of old manufactured goods; production of a traditional good plus a growing number of copied goods previously produced in the North; all these plus a growing number of innovative goods; and finally at the 'highest' stage, the cessation of copying. These four stages emerge in our analysis as four possible *equilibria* with the North innovating and possibly engaging in some traditional activity. We will show that the factors that determine which of these stages exist are the speed which the South absorbs ideas from the North; the factor endowment in the North and South; the relative ease of copying ($1/a_c$) and finally the relative inefficiency of the South (β_j in sector j).

Now consider the profit-maximising pricing strategies for *innovative* and *copied* goods. For the former, using (3), prices and profits are given by:

$$p_i^b = C_m^b(\mathbf{w}^b)/\alpha; \quad \pi_i^b = (1-\alpha)p_i^b x_i^b; \quad b = N, S, \tag{14}$$

For Southern copying firms we distinguish a *narrow-gap* case, $\alpha C_m^N < C_m^S < C_m^N$ where there exists only a small cost advantage and a *wide-gap* case $C_m^S < \alpha C_m^N$. In

[9] For a Northern firm to copy it would have to charge a limit price to rule out a new Northern or Southern entrant, and hence would earn zero or negative profit. However in Segerstrom (1991) firms can collude and then the North can engage in both innovation and copying

the wide-gap case Southern firms can charge the full monopoly price giving price and profits:

$$p_c^S = C_m^S/\alpha; \quad \pi_c^S = (1-\alpha)p_c^S x_c^S \tag{15}$$

In the narrow-gap case, however, the Southern firm must charge a *limit price* just sufficient to eliminate a potential Northern rival, i.e.,

$$p_c^S = C_m^N; \qquad \pi_c^S = (C_m^N - C_m^S)x_c^S. \tag{16}$$

Imitation in the Southern R&D sector is cheaper than innovation, but the cost of producing innovative and copied goods in the manufacturing sector is the same. For these activities to co- exist in phase III it follows that Southern innovative goods must sell at a higher price. This is possible in a narrow-gap equilibrium where copied goods charge a limit price giving a lower mark-up on costs than that of innovative goods. It is not possible in a wide-gap equilibrium where both types of good sell at the same mark-up over costs. We conclude that *in stage III of Southern development, only a narrow-gap equilibrium exists for copied goods, but both wide-gap and narrow gap equilibria are possible in phase II.*

In order to assign world demand to manufactured goods produced in the two regions we now use the demand function (5) to yield the following relative demand relationships for the wide-gap and narrow-gap copying cases respectively

$$\frac{x_c^S}{x_i^N} = \left(\frac{p_c^S}{p_i^N}\right)^{-\varepsilon} = \left[\frac{C_m^S(\mathbf{w}^S)}{C_m^N(\mathbf{w}^N)}\right]^{-\varepsilon}; \quad \frac{x_c^S}{x_i^N} = \alpha^{-\varepsilon}. \tag{17}$$

When innovation also exists in the South we have an analogous relationship

$$\frac{x_i^S}{x_i^N} = \left(\frac{p_i^S}{p_i^N}\right)^{-\varepsilon} = \left[\frac{C_m^S(\mathbf{w}^S)}{C_m^N(\mathbf{w}^N)}\right]^{-\varepsilon}. \tag{18}$$

Knowledge capital has been introduced in the specification of the R&D production function (11) and this drives endogenous growth in models of this genre. The basic idea is that a new or copied blueprint emerging in the R&D sector contains new ideas and information useful to future generations. Knowledge capital is then a stock which increases with the world's accumulated research experience of producing innovative or copied goods. A general formulation would allow gradual knowledge diffusion with different inter-regional and intra- regional rates of diffusion. However, in order to highlight the asymmetrical North-South aspects of the model we assume that ideas diffuse instantaneously within both regions and from North-to-South, but South-to-North diffusion is gradual. A specific formulation capturing these ideas is

as follows. Northern knowledge capital is given by $K^N = n_i^N + n_c^S + n_i^S = n$. Thus, as in GH and Lai (1998), we proxy Northern knowledge capital by the number of varieties (n) in the world. On the other hand, diffusion from North to South takes longer, so that $K^S = n_c^S + n_i^S + K^{SN}$ where K^{SN} is the component of Southern knowledge capital that is *gradually* absorbed from the North. Defining κ as this rate of diffusion of knowledge, we can write

$$\dot{K}^{SN} = \kappa(n_i^N - K^{SN}), \tag{19}$$

Thus if North-to-South spillovers occur ($\kappa > 0$), knowledge capital in the South increases as a result of innovation in the North. If diffusion is instantaneous ($\kappa = \infty$), $K^{SN} = n_i^N$ and $K^S = K^N = n$. If only the North innovates (which is the case in Southern stages I and II defined below) spillovers are one-sided, flowing only from North to South [10].

Turning to the financial sector, let the stock market value of the typical R&D firm in the production sectors producing innovative goods in the North and South and imitated goods in the South be v_i^N, v_i^S, v_c^S respectively. From (11), a new blueprint in the North costs $C_i^N(\mathbf{w}^N)/K^N$, where the cost function C_i^N is defined as for the traditional and manufacturing sectors, and the NPV rule requires this to be equated with v_i^N. The same argument applies to innovation and imitation in the South giving

$$v_i^N = C_i^N(\mathbf{w}^N)/K^N, \quad v_i^S = C_i^S(\mathbf{w}^S)/K^S, \quad v_c^S = C_c^S(\mathbf{w}^S)/K^S. \tag{20}$$

We assume perfect capital mobility between production and R&D sectors in each region, but not capital mobility between regions. In the North the typical firm must take into account that, during the period of time dt, it will be imitated by the South and forced out of business with probability $\dot{n}_c^S/n_i^N dt$. This gives the no-arbitrage condition

$$\frac{\pi_i^N}{v_i^N} + \frac{\dot{v}_i^N}{v_i^N} - \frac{\dot{n}_c^S}{n_i^N} = r^N. \tag{21}$$

In the South, the four stages of development give the no-arbitrage conditions below. Equation (22) says that the return on R&D investment in copying (profits plus

[10] van de Klundert and Smulders (1996) study a North-South endogenous growth model with one-sided knowledge spillovers from North to South. In their model endogenous growth is driven by 'learning by doing' in contrast with the GH framework here where innovation brings about long-term growth. They also focus on convergence or non-convergence of regions to a common long-term growth path. It turns out that our model is saddle-path stable and therefore exhibits convergence

capital gain) is less than the rate of interest and will therefore not take place. Equation (23) is the no-arbitrage condition for R&D investment into copying and the condition for R&D investment into innovation not to be viable. Equation (24) is the no-arbitrage condition for R&D investment into copying and innovation to co-exist. Finally, (25) is the condition for innovating R&D but not copying R&D to exist.

Stage I: Traditional Only

$$\frac{\pi_c^S}{v_c^S} + \frac{\dot{v}_c^S}{v_c^S} < r^S; \tag{22}$$

Stage II: Traditional and Copying

$$\frac{\pi_i^S}{v_i^S} + \frac{\dot{v}_i^S}{v_i^S} < r^S = \frac{\pi_c^S}{v_c^S} + \frac{\dot{v}_c^S}{v_c^S}. \tag{23}$$

Stage III: Traditional, Copying and Innovation

$$\frac{\pi_i^S}{v_i^S} + \frac{\dot{v}_i^S}{v_i^S} = \frac{\pi_c^S}{v_c^S} + \frac{\dot{v}_c^S}{v_c^S} = r^S; \tag{24}$$

Stage IV: Traditional and Innovation

$$\frac{\pi_c^S}{v_c^S} + \frac{\dot{v}_c^S}{v_c^S} < r^S = \frac{\pi_i^S}{v_i^S} + \frac{\dot{v}_i^S}{v_i^S}. \tag{25}$$

The skilled and unskilled labour market clearing conditions are:

$$a_{Li}^N(\dot{n} - \dot{n}_i^S)/K^N + a_{Lm}^N n_i^N x_i^N + a_{Lz}^N Z^N = \bar{L}^N, \tag{26}$$

$$a_{Lc}^S \dot{n}_c^S/K^S + a_{Li}^S \dot{n}_i^S/K^S + a_{Lm}^S(n_c^S x_c^S + n_i^S x_i^S) + a_{Lz}^S Z^S = \bar{L}^S; \tag{27}$$

$$a_{Hi}^N(\dot{n} - \dot{n}_i^S)/K^N + a_{Hm}^N n_i^N x_i^N + a_{Hz}^N Z^N = \bar{H}^N, \tag{28}$$

$$a_{Hc}^S \dot{n}_c^S/K^S + a_{Hi}^S \dot{n}_i^S/K^S + a_{Hm}^S(n_c^S x_c^S + n_i^S x_i^S) + a_{Hz}^S Z^S = \bar{H}^S. \tag{29}$$

In the model as it stands there exists one equilibrium of trajectories corresponding to each long-run accumulation of net assets/liabilities by the regions. The latter however is indeterminate; we can either proceed by imposing a net asset/liability position, or else assume capital immobility, so that trade is balanced in each period.[11] We choose the latter, which implies

$$E^N = p_i^N n_i^N x_i^N + p_z Z^N; \quad E^S = p_c^S n_c^S x_c^S + p_i^S n_i^S x_i^S + p_z Z^S, \tag{30}$$

[11] This problem of multiple equilibrium trajectories is a familiar one for open-economy models based on intertemporal optimization by households. For further discussion see GH, chapter 8.

and equating demand and supply for the traditional good we have

$$Z^N + Z^S = \frac{1-\theta}{\theta p_z}(p_i^N n_i^N x_i^N + p_c^S n_c^S x_c^S + p_i^S n_i^S x_i^S), \tag{31}$$

Wealth in each region takes the form of equity $W^N = n_i^N v_i^N$ in the North and $W^S = n_i^S v_i^S + n_c^S v_c^S$ in the South and wealth accumulates according to (8). In fact using the arbitrage conditions budget constraints (8) can be shown to be national income identities and are superfluous. There is nothing to pin down the price level in our model and we choose the Northern skilled wage as numeraire.

This completes the trade model. To assess the gains from trade we compare this with a benchmark *autarky* model in which both regions produce the traditional good, both regions innovate, but the South does so relatively inefficiently, and no knowledge spillovers occur.

3 The Steady State: Some General Results and Special Cases

We now examine the steady state of the model set out in the previous section. First we derive a result where the South is uniformly inefficient in all activities i.e. $\beta_z = \beta_m = \beta_r$ in (12), and then we examine the more general case where relative inefficiency is not uniform across sectors. In both cases we find the necessary conditions for Southern copying to exist.

We study a balanced-growth steady state in which the product shares and North-South knowledge capital ratios are constant, the total market value of each production sector is constant, and interest rates and growth rates of copied and innovative goods in both regions are equal. Of course this steady state is only meaningful if the model is locally stable in the vicinity of that state — in the absence of stability growth rates in the two blocs can diverge.[12] In a technical appendix, available on request, we derive the dynamics of the system, and investigate stability using a linearized model. Since the growth rate and the stock market values v_r^b are forward-looking, saddle-path stability requires that there are two unstable eigenvalues. Reassuringly, for our central calibration and variations of each parameter in turn about

[12]Feenstra (1996) studies a version of our model in stage IV of Southern development in which manufactured varieties are intermediate inputs into trade final goods, but the inputs themselves are not traded. Then if inter-region knowledge spillovers are absent he finds the model to exhibit divergence in long-term growth rates. In our set-up stages of development are endogenous and partly determined by the North to South spillover effect. When this effect is low we find that the South will in fact be in a lower stage of development

these values we find that stages, I, II and IV are saddle-path stable, while stage III is saddle-path stable if we assume that copying becomes easier as the copying sector increases in size (since policing patent agreements becomes more difficult) i.e., a_c is decreasing in the share of copied products. If a_c is either constant or increasing in the share of copied products – as a result of copying becoming harder once the easier products have been copied – the system is characterised by a different form of stability: the South starts off either only copying or only innovating, depending on initial conditions. When the configuration of variables such as growth rates, Southern share of copied and innovative goods is such that the returns to copying and innovation are the same, then the system continues along Stage III towards the steady-state. For further details see the technical Appendix.

To characterize the steady state, define $\xi_i^N = n_i^N/n$, $\xi_i^S = n_i^S/n$, and $\xi_c^S = n_c^S/n$ as the shares of the three types of products in the two regions. Let $g = \dot{n}/n$ be the world growth rate of varieties, $c = \dot{n}_c^S/n_i^N$ the rate at which the South copies the North and let $k = K^S/K^N$ be the ratio of knowledge capital in the South to that of the North. Full details of the steady state are set out in Appendix A. Using these we first prove a general result for this steady state when all β_j are the same, which shows that a necessary condition for any copying to occur alongside traditional activity is that the North-to-South knowledge diffusion rate κ must be finite.

Proposition 1. *Assume β_j are equal across sectors. Then when knowledge capital spillovers are instantaneous ($\kappa = \infty$) and both regions produce the traditional good, (i) no Southern copying occurs (ii) the skilled/unskilled wage ratio is the same in North and South.*

Proof. We prove this by contradiction. Copying occurs when the South is in either stage II or III. Consider the latter first. We know that for copying to exist alongside imitation in stage III the equilibrium must be a narrow-gap type with limit pricing for manufactured goods. Then the cost of manufacturing in the South must be less than that in the North, i.e., $C_m^S < C_m^N$. Dividing this equation by the equality (A.14), using the assumption of Cobb-Douglas production functions,[13] leads to $w_H^N/w_L^N > w_H^S/w_L^S$. Now suppose that copying and innovation exist together; from (A.12) $k = 1$ as $\kappa \to \infty$. Then using $C_m^S/C_m^N < 1$, (A.4), (A.6), and (A.8)

[13]It is also possible to prove this result for any constant returns to scale production function with no factor intensity reversals. The latter assumption, which holds when all elasticities of substitution are the same, eliminates the possibility that under trade, relative factor price equalisation might not hold; if it did, then for a range of factor prices, both North and South would want to export the same factor-intensive goods.

we see that $C_i^S > C_i^N$. Dividing this by (A.14), yields a contradictory inequality $w_H^N/w_L^N < w_H^S/w_L^S$. A similar proof shows that Southern stage II cannot occur for the narrow gap case.

Now consider the Stage II wide gap case. Firstly we have $C_m^S < \alpha C_m^N < C_m^N$. Then dividing (A.7) by (A.8) and substituting from (A.4) we have $1 > \frac{r+g}{r+g+c} = \frac{C_m^S}{C_c^S}\frac{C_i^N}{C_m^N}(\frac{C_m^S}{C_m^N})^{1-\varepsilon}$. Using the relationship between Southern costs of copying and innovation $C_c^S = a_c C_i^S$, this can be rewritten as $\frac{C_i^S}{C_i^N} > \frac{1}{a_c}(\frac{C_m^S}{C_m^N})^{1-\varepsilon} > 1$; this last inequality holds because $a_c < 1$. Thus we end up with the same contradiction as for the narrow gap case.

Finally, since there is no copying it follows that $C_m^S = C_m^N$. Dividing this by $C_z^S = C_z^N$ yields $w_H^S/w_L^S = w_H^N/w_L^N$. □

The intuition behind this proposition is very straightforward if $\beta_j = 1$. Then with $\kappa = \infty$, different factor endowments provide the only difference between regions. In the absence of specialisation we then have factor price equalisation and the Southern firm has no incentive to copy for the same reason as in the North. For the case of Southern relative inefficiency, $\beta_j = \beta > 1$, each worker in the North is equivalent to β workers in the South and the same argument applies once the units of labour are appropriately adjusted.

Now suppose that Southern relative inefficiency in the three sectors, β_z, β_m and β_r, are different. The following proposition establishes a necessary condition for stage II or III to exist under the same conditions as proposition 1.

Proposition 2. *Recall the assumption $\gamma_r \geq \gamma_m \geq \gamma_z$ and let $\nu = (\gamma_r - \gamma_m)/(\gamma_r - \gamma_z)$. Then when knowledge capital spillovers are instantaneous, and both regions produce the traditional good, a necessary condition for copying to occur is that $\beta_m < \beta_z^\nu \beta_r^{1-\nu}$.*

Proof. The proof is based on that of the proof above. The only difference is that the two inequalities for relative wages transform to

$$(\beta_m/\beta_z)^{1/(\gamma_m-\gamma_z)} w_H^S/w_L^S < w_H^N/w_L^N < (\beta_r/\beta_z)^{1/(\gamma_r-\gamma_z)} w_H^S/w_L^S \tag{32}$$

A necessary condition for it to hold is $(\beta_m/\beta_z)^{1/(\gamma_m-\gamma_z)} < (\beta_r/\beta_z)^{1/(\gamma_r-\gamma_z)}$;
ie $\beta_m < \beta_z^\nu \beta_r^{1-\nu}$. □

The intuition behind this result is as follows. Copying can only exist if the South can manufacture at a lower cost than in the North. This imposes a restriction on the relative inefficiency of that sector compared with the traditional sector or R&D. If β_r/β_m becomes too low then Southern innovation will be preferred to copying and only phase IV is possible. If β_z/β_m is too low then traditional activity is

preferred to manufacturing in the South and only stage I is possible. It should be emphasised that this result holds if North-to-South knowledge capital diffusion rates are instantaneous and the traditional sector existing in both regions. It follows from this analysis that copying can occur only if we allow for one of the following: traditional activity only in the South, non-uniform relative inefficiency or gradual North-to-South knowledge capital diffusion rates. In the rest of the paper we have chosen to analyze in detail just one of these cases. We have chosen the route of gradual knowledge capital transfusion rates primarily because it is the more obvious extension of the work of GH, which is widely regarded as the seminal work in this area. From now on therefore we shall assume that $\beta_z = \beta_m = \beta_r = \beta$, say, and that $\kappa < \infty$.

Now return to the factor price equalisation result in Proposition 1, $w_H^S/w_L^S = w_H^N/w_L^N$, which holds when knowledge diffusion is instantaneous. When this assumption is relaxed we then have the following:

Proposition 3. *If both regions produce the traditional good and* $\kappa < \infty$ *then* $w_H^S/w_L^S < w_H^N/w_L^N$.

Proof. Consider firstly the case of copying, which will only occur if $C_m^S < C_m^N$. If both produce the traditional good, then $C_z^S = C_z^N$, and dividing this into the previous inequality yields $(w_H^S/w_L^S)^{\gamma_m - \gamma_z} < (w_H^N/w_L^N)^{\gamma_m - \gamma_z}$ and hence the result. Alternatively suppose no copying takes place. Now consider the case of innovation only. Dividing (A.6) by (A.7) and sustituting from (A.4) yields $(C_m^S/C_m^N)^{\epsilon-1} C_i^S/C_i^N = k$. Dividing this by $C_z^S = C_z^N$ raised to the power ϵ yields $(\frac{w_H^S/w_L^S}{w_H^N/w_L^N})^{(\gamma_m-\gamma_z)(\epsilon-1)+\gamma_i-\gamma_z} = k < 1$. The result then follows. □

Thus the effect of gradual as opposed to instantaneous North-to- South knowledge diffusion is to make the skilled/unskilled wage ratio in the South lower than that of the North, in the steady state. This is exactly what one would expect, since gradual knowledge diffusion from the North (as opposed to instantaneous transfusion in the opposite direction) means that the *stock* of knowledge capital in the South is less than that in the North in the steady state. It then follows that R&D activity in the South region is relatively inefficient which reduces the relative demand for skilled labour which is used more intensively in that activity. As we shall see in subsequent simulations, an increase in the knowledge capital diffusion rate causes the South to progress through the stages of development, but propositions 1 and 3 do not tell us how the skilled-unskilled ratio in the regions change as this happens. Standard Heckscher- Ohlin theory tells us that a progression from autarky to trade sees the skilled-unskilled wage ratio rise in the North and fall in the South. Numer-

ical simulations in the next section show that the opposite happens as the South progresses through the stages as a consequence of κ increasing; this is consistent with our propositions, but we are unable to prove this result analytically.

In the rest of this section we examine an analytical characterisation of the full equilibrium under restrictive assumptions that innovation or copying uses only skilled labour (i.e., $\gamma_i = \gamma_c = 1$), while the traditional good requires only unskilled labour (i.e., $\gamma_z = 0$). From (9), the latter assumption implies that $w_L^N = \beta w_L^S$ unless the North specialises in manufactured goods. Consider stage II in the South. In our simulations there seems to be little evidence for a wide-gap equilibrium, so we focus on the narrow-gap equilibrium. Using (A.4), (A.8), and (A.10), it is then straightforward to show that the following relationship between growth and Southern copying holds

$$A_i^N[g + \gamma_m \xi_i^N (r + g + c)\alpha/(1-\alpha)] = \bar{H}^N. \tag{33}$$

where r is given by (A.3). When there is no innovation in the South, from (A.1), $\xi_i^N = g/(g+c)$, and it is easy to show that for $\sigma < 1$, (33) yields a *positive* relationship between growth and copying. Thus we have the proposition:

Proposition 4. *In Southern stage II in the narrow-gap equilibrium if research requires only skilled labour and the traditional good requires only unskilled labour, then an increase in copying by the South increases world growth.*

Proposition 4 corresponds to the results of GH (and is discussed further in Lai (1998)), obtained for a model with only one type of labour and no traditional sector. The intuition is that an increase in the rate of copying in stage II raises the effective Northern cost of capital which tends to discourage innovation in that region. At the same time copying transfers the proportion of varieties produced in the South which releases Northern workers, formerly employed in manufacturing, into the labour market. Under the assumptions of proposition 3, *all* the released skilled workers find their way into the R&D sector and this will tend to boost that activity. If the latter effect is greater than the former, more Northern innovation is encouraged and world growth of new varieties increases with a higher proportion of them being manufactured in the South. In fact with Cobb-Douglas preferences and production functions this turns out to be the case and the *positive* relationship between the rate of Southern copying and world growth is established. However, if the assumptions of Proposition 4 are violated, in particular if the traditional good also requires skilled labour, then the R&D and traditional sectors must compete for both types of labour. Then some skilled workers released from manufacturing end up in the traditional

sector thus reducing the second effect alluded to above. Then growth may fall and the relationship between Southern copying and growth is *negative*. Indeed, in the simulations of section 4 we find this is the case.

Now continue to assume production functions as before, but assume β and κ are such as to sustain stage IV in the South. The equations for market clearing in the North and South skilled labour are then:

$$A_i^N \xi_i^N [g + \gamma_i (r+g)\alpha/(1-\alpha)] = \bar{H}^N, \tag{34}$$

$$\beta A_i^N (1-\xi_i^N)/k [g + \gamma_i (r+g)\alpha/(1-\alpha)] = \bar{H}^S. \tag{35}$$

Then substituting for r from (A.3), it is straightforward to show that the relationship between g and ξ_i^N is downward sloping for the North and upward sloping for the South. An increase in the diffusion rate shifts (35) to the right, raising growth and lowering the Northern share of manufactured goods. Thus we have:

Proposition 5. *In stage IV in the South, when innovation displaces copying and under the same assumptions of Proposition 4 an increase in κ raises growth and lowers the Northern share of manufactured goods.*

The intuition here is similar to before except now there is no increase in the effective cost of capital from Southern copying. A contraction of Northern manufacturing releases skilled workers into the R&D sector and the opposite happens in the South. Because the South is less efficient and has a lower stock of knowledge capital, the net effect on world innovation is positive and world growth rises.

4 The Gains from Trade and the International Diffusion of Knowledge: Numerical Results

The analysis of section 3 has provided us with some partial insights into the properties of the model, but not with the full solutions to the equilibria. For these we require numerical computations to which we now turn. The details of the calibration are given in Appendix B.

4.1 Stages of Development

Figure 1 shows how the Southern relative inefficiency (β), the relative cost of copying (a_c), the proportion of skilled workers in the South ($\bar{H}^S$), and the North-South

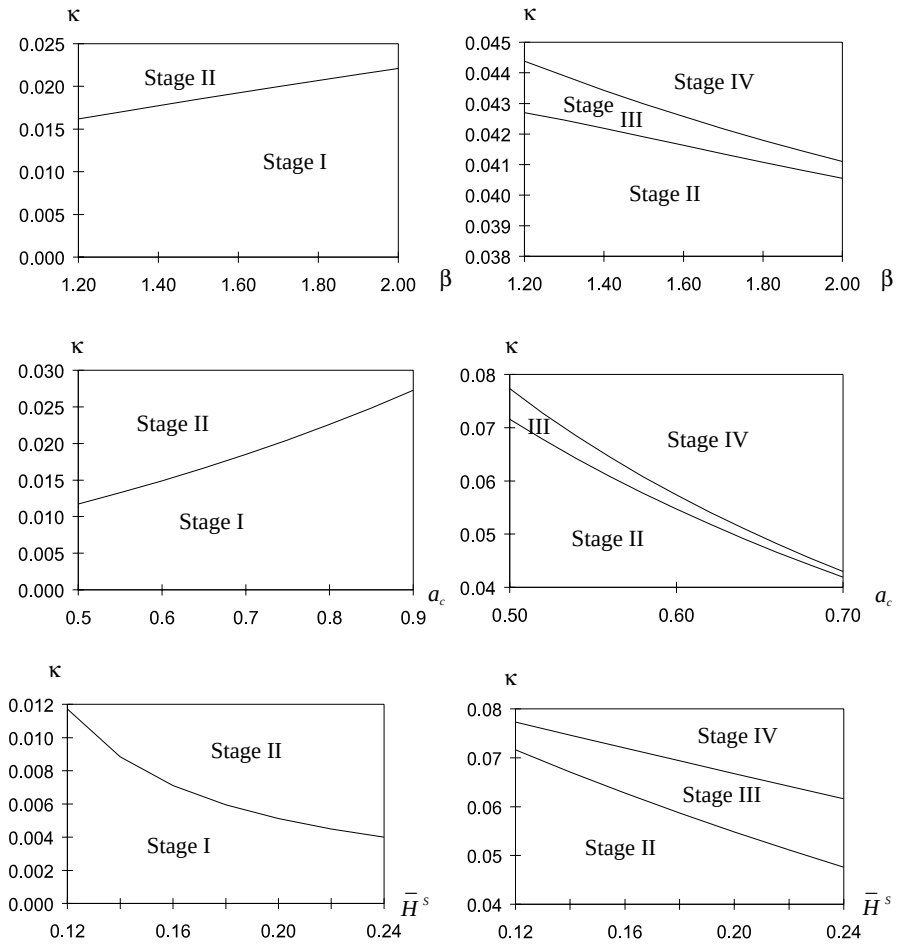


Figure 1: Stages of development as equilibria: the impact of knowledge diffusion and relative inefficiency (β), the relative cost of copying (a_c), and the Southern skill-labour proportion ($\bar{H}^S$). Each horizontal pair of figures are sections of the sane large figure—left-hand figures are for 'low' κ, right-hand figures are for 'high' κ

knowledge diffusion rate (κ) combine to produce our four stages of Southern development. For a given pair of values of κ with any one of the other parameters, one can read off from the figures the appropriate stage of development in the South. Then an increase in κ for a given β, a_c, and $\bar{H}^S$ enables the South to progress through the four stages of development.[14]

[14]Exogenous variables κ and $\bar{H}^S$ could be linked by making knowledge assimilation by the South a function of its human capital proportion. Similarly, κ and β could be linked in the same fashion. Southern development in (κ, β) and $(\kappa, \bar{H}^S)$ space would then be captured by movements in a North-east direction in Figure 1. Drawing out these linkages and developing an explicit theory of knowledge diffusion is left to future research (see comments in the conclusions).

Suppose β or a_c changes with the latter being interpreted as a change in the degree of patent protection. An increase in β or a_c has two effects: for a low North-South knowledge diffusion rate κ, it forces the South to specialise in the traditional good in development stage I. By contrast for higher κ an increase in β and/or a_c promotes innovation at the expense of copying. This is what one would expect of patent protection. The reason why an increase in Southern relative inefficiency across all sectors has a similar effect is that copying is a narrow-gap equilibrium for our calibrated model. This involves limit pricing for which an increase in inefficiency squeezes profits. By contrast under innovation prices are a mark-up over costs and so a uniform rise in Southern relative inefficiency can actually encourage innovation over copying.

Unlike changes in relative inefficiency and a strengthening of patent protection, the effect of skill catch-up by the South is unambiguous. At all values of κ, 'higher' stages of Southern development are encouraged as $\bar{H}^S$ increases. More skilled workers increases R&D activity. In stage I copying becomes more advantageous and eventually stage II is reached. Thereafter innovation which requires more skilled workers to achieve a blueprint than copying, is encouraged and the equilibria proceed through the stages as the pool of available skilled labour increases. To summarise:

Numerical Result 1. *Ceteris paribus, an increase in the North-South knowledge diffusion rate κ enables the South to progress to a higher stage. An increase in either Southern inefficiency (β) or international patent protection (a_c) has two effects depending on the speed of North-South knowledge diffusion (κ). For low κ it enforces Southern specialisation in the traditional good. For high κ it encourages innovation in the South at the expense of copying. For all κ, an increase in the proportion of skilled workers in the South favours a progression into a higher development stage.*

4.2 From Autarky to Trade

Table 2 sets out the full solution to the four stages for our baseline calibration. Also shown for comparison is the outcome under autarky in which no trade takes place and there are no international knowledge spillovers. We now examine what happens when we move from autarky to trade in which the South is in stage I. From Figure 1, this is the appropriate stage for the South if κ is small. Whereas under autarky the South produces some high-tech manufactures, the trade equilibrium sees the South specialising in the production of the unskilled labour-intensive traditional good. From Table 2 we see that the North produces more of the high-tech skilled

labour-intensive manufactured good and devotes more resources to the most skilled labour-intensive sector, R&D, compared with autarky.

The Heckscher-Ohlin theorem – that each region exports the good making relative intensive use of its relatively abundant factor – then carries over to our trade model with endogenous growth; the integrated world economy now grows at a higher rate than either of the former autarkic regions.[15] In the North this shift in production sees the demand for skilled workers increase and that for unskilled workers decrease. The unskilled/skilled wage ratio therefore falls in the North. In the South the opposite happens. What happens to the welfare of these four groups? Under trade the South specialises in the production of a good produced under competitive conditions whereas the North produces more of the monopolistic good. Monopoly profits are therefore transferred from the South to the North. In the notional absence of growth the South would be 'exploited' and lose out under trade. Despite being exploited in this sense, the South does not lose out however. This is because the transfer of monopoly profits to the North serves to increase R&D investment and with it world growth in new varieties. This benefits both North and South. Taking this into account, our welfare calculations show that unskilled workers in both the North and the South join the winners from trade, and only the small proportion of Southern skilled workers lose out. We summarise these results as:

Numerical Result 2. *The Heckscher-Ohlin (H-O) theorem generalises to our trade model with endogenous growth: each bloc exports the good making relatively intensive use of its relatively abundant factor. For low knowledge diffusion from the North, the South specialises in the traditional competitive good, the North produces more of the high-tech manufactured monopolistic good, devotes more resources to R&D, and world growth rises. Of the four groups of workers: skilled and unskilled, North and South, only the Southern skilled workers see a reduction in welfare, as a consequence of trade.*

[15] Our result is in contrast with that of GH, chapter 9, where in a two-country model corresponding to ours with the South in stage IV, with equal efficiency and with instantaneous knowledge diffusion ($\kappa = \infty$) under both autarky and trade, a skilled labour rich country integrating with an unskilled labour rich country may actually lead to it growing by less. This would be a possibility in our model if increased κ sufficiently so that the South is in stage IV with trade, and allowed for knowledge capital spillovers even under autarky.

Table 2: Simulation Results

Stage	**Autarky**	**I**	**II**	**III**	**IV**
Knowledge Diffusion	–	0.019	0.032	0.042	1000
World Shares of Innovation Goods (%)					
North		100	100	98	82
South		–	–	2	18
Size of Traditional Sector					
North (Z^N)	0.31	0.10	0.12	0.13	0.20
South (Z^S)	0.23	0.45	0.42	0.42	0.34
Size of Manufactured Sector					
North (X_i^N)	0.20	0.27	0.26	0.26	0.23
South ($X_c^S + X_i^S$)	0.10	0.00	0.02	0.02	0.05
Wages					
N. Skilled	1.00	1.00	1.00	1.00	1.00
N. Unskilled	0.48	0.32	0.34	0.34	0.40
S. Skilled	0.67	0.27	0.34	0.36	0.67
S. Unskilled	0.17	0.25	0.25	0.25	0.27
S. Unskilled/Skilled Ratio	0.25	0.93	0.74	0.69	0.40
Growth (%)	2.00*	4.14	4.06	4.11	4.65
Copying Rate (%)	–	–	0.07	0.05	–
Welfare (Utility)†					
N. Skilled	102.3	115.2	114.8	114.6	113.0
N. Unskilled	72.2	79.6	80.5	80.9	83.9
S. Skilled	99.3	45.6	62.5	67.9	98.3
S. Unskilled	0	37.3	37.7	38.7	47.3

*The average of the *different* growth rates (see Appendix B).

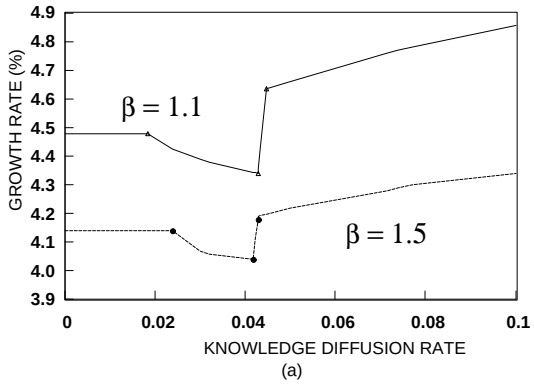
†Utility is measured relative to that of the unskilled Southern worker under autarky. This refers to welfare in the steady state, and does not give the welfare improvements for the *transition* between stages, although the value is correct for the shift from autarky to stage I, since the transition is instantaneous. Results for $\sigma = 1$ using the full dynamic model indicate that dynamic and steady-state welfare gains are similar.

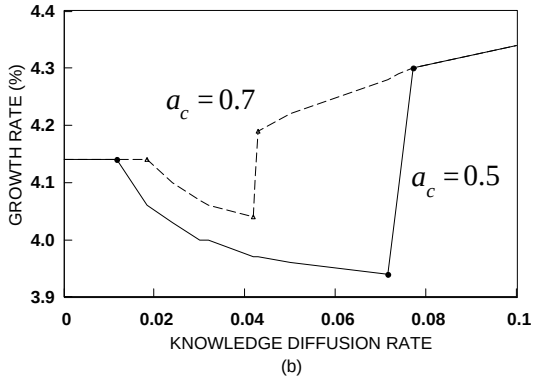
4.3 Progressing Through the Stages

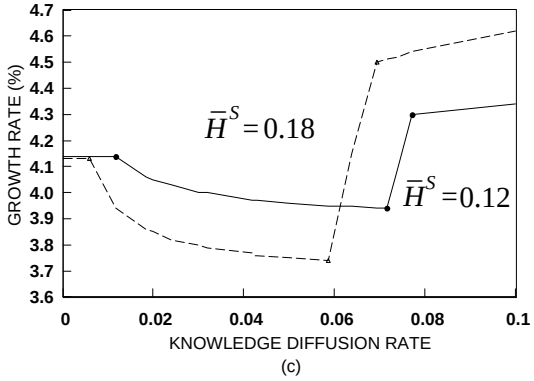
We have discussed what happens to world growth as we proceed from autarky to trade when North-South knowledge spillovers are very slow. Now suppose knowledge spillovers are faster. The South then proceeds through stages II to IV. However, from Table 2 world growth actually *decreases* in stage II. An increased rate of copying by the South is now associated with lower world growth thus overturning the result reported in Proposition 4. As discussed after proposition 2, the reason for this is that an increase in copying in the South had two opposite effects on the incentive to innovate in the North. The prospect of a Northern innovator being displaced by a Southern imitator tends to reduce this incentive and reduce growth. However those remaining Northern producers of innovative goods now face less competition for factors of production. If the traditional sector employs no skilled labour then the released labour of this type must find its way into R&D and the cost of this activity falls. But if some skilled labour finds its way into the Northern traditional sector the disincentive effect can dominate and this is in fact what happens here in Table 2. Growth *decreases* in stage II as copying increases but begins to rise in stage III as innovation in the South takes off. Figure 2 shows how the (κ, g) profiles depend on the degree of patent protection, a_c, and the proportion of workers who are skilled in the South, $\bar{H}^S$. Figure 2(a) shows that an increase in Southern relative efficiency (a reduction in β) increases world growth in all stages but has little effect on the Southern progression through the stages. In Figure 2(b), we see that increasing patent protection similarly increases world growth in stages II and III where copying occurs.[16] Its effect on the South is ambiguous because it delays its progression from stage I to stage II, but advances its progression to III and IV as the diffusion rate increases. Figure 2(c) shows that the increase in the proportion of Southern skilled labour ($\bar{H}^S$) has an even more ambiguous effect. In stage II the increase in $\bar{H}^S$ increases the rate of copying and this discourages Northern innovation. World growth *decreases*, compared with the case of less skilled workers. However the transition to stage III takes place at a lower diffusion rate. From that point onwards world growth *increases*.

Now we go back to table 2 to examine who are the winners and losers as κ increases and the South moves through stages of development. As the South develops a high-tech manufacturing industry in stages II to IV and switches away from the

[16] A similar result can be seen in Lai (1998) where imitation can only occur as a result of foreign direct investment, and in Acemoglu and Zilibotti (1999) where protection induces Northern R&D firms to develop machines complementing unskilled labour.







Note: The nodes • represent boundaries of different stages.

Figure 2: Growth against diffusion rate as β, a_c and $\bar{H}^S$ change.

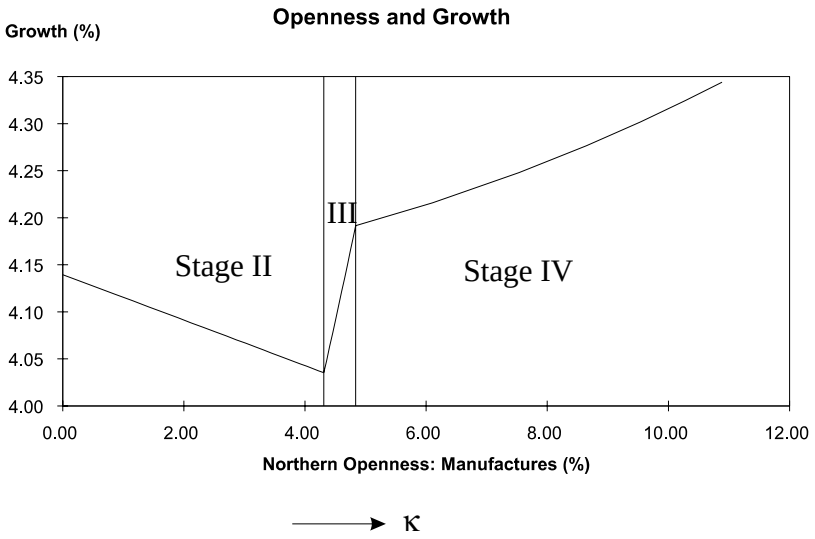


Figure 3: Northern Openness and Growth.

traditional sector, it experiences a relative increase in demand for skilled labour and a decrease in the unskilled/skilled wage ratio. The opposite happens in the North. Associated with these switches in activity in the two regions is a reduction in Northern 'exploitation' or 'unequal exchange' because less monopoly profits are transferred from South to North. Overall this change and the increase in growth through stages III and IV, sees the South gaining significantly in welfare terms. The North as a whole loses with the welfare loss falling on the skilled workers. However compared with autarky both skilled and unskilled workers in the North are still better off. At the extreme, when κ is very large and North-South knowledge diffusion is instant, the only losers from trade—Southern skilled workers—are very close to their welfare levels under autarky. For different parameter values (say a decrease in β) growth will be stronger and a scenario of no losers is then possible. To summarise:

Numerical Result 3. *As the speed of North-South knowledge diffusion increases the South proceeds through stages I to IV. In stage II, higher copying discourages innovative R&D in the North and world growth decreases. When the South starts to innovate in stages III and IV, growth increases. These changes are accompanied by a reduction in the transfer of monopoly profits to the North, an increase in welfare for both Southern groups and a decrease in welfare for Northern skilled workers.*

Finally, we examine the relationship between openness and growth. The steady-state level of trade may be calculated by observing that North and South consume

all goods in the same proportion. Let $\lambda = E^N/(E^N + E^S)$ be the proportion of Northern income. With the North exporting only manufactured varieties, the value of its gross exports is given by $(1-\lambda)p_i^N n_i^N x_i^N = \chi_m^N$. Similarly, Southern manufactured exports are $\lambda[p_i^S n_i^S x_i^S + p_c^S n_c^S x_c^S] = \chi_m^S$ say, where $x_i^S = 0$ in stage II and $x_c^S = 0$ in stage IV. Then we define *Northern Openness* in manufactures (NO) as Southern manufactured exports to the North as a proportion of total Northern demand for manufactures:

$$NO = \frac{\chi_m^S}{X_i^N - \chi_m^N + \chi_m^S}. \tag{36}$$

Figure 3 shows that as κ increases, the value of NO increases. The reason for this is straightforward: as North-to-South knowledge diffusion increases the Southern manufacturing sector increases in size and some of these goods are exported to the North. It follows from the relationship we have established between growth and κ that Northern Openness with the South is *negatively* correlated with growth in stage II and is only *positively* correlated with growth once the South begins to innovate in stage III.

5 Conclusions

This paper has developed an integrated 'new growth, new trade' framework that links patterns of North-South trade with four stages of development in the South: specialisation in a traditional good; a stage where the South in addition copies Northern innovative manufactured goods producing product cycles; a third stage where the South begins to innovate in its own right and finally a stage in which the South only innovates as in the North. These four stages of development emerge as possible equilibria determined by the relative across-the-board efficiency of the South compared with the North, the speed of North-South knowledge diffusion, Southern relative endowment of human capital and the degree of patent protection. The model is then used to examine the relationship between patent protection and world growth, the welfare gains from North-South trade and the distribution of these gains between regions and factors of production.[17]

The new (endogenous) growth aspect of the model highlights the dynamic aspects of these traditional trade issues. Whereas in a static H-O framework the

[17]Since knowledge capital diffusion rates are exogenous in our model, our theory would benefit from incorporating an explicit theory of how knowledge diffuses across populations and through time drawing, for example, on Karshenas and Stoneman (1995), and Weitzman (1998).

Table 3: Winners and Losers under Trade: A Comparison of Predictions of H-O and New Trade-New Growth Theories.

Groups	H-O	New Trade-New Growth	
		Low κ	High κ
North Skilled	Winners	Winners	Winners
North Unskilled	Losers	Winners	Winners
South Skilled	Losers	Losers	Winners?
South Unskilled	Winners	Winners	Winners

winners are skilled workers in the North and unskilled workers in the South, in our framework the dynamic gains from trade create additional winners—unskilled workers in the North. If the international diffusion of knowledge capital from North to South is sufficiently rapid then our results suggest the possibility that the remaining group, skilled workers in the South, could also become beneficiaries from trade. The conclusions are summarised in Table 3.

In our model, and others of this genre, knowledge capital is a public good. It follows that the level of private investment in R&D which adds to the stock of knowledge capital and drives growth, is socially sub-optimal. There is therefore a role for governments to provide public support for R&D. However our research shows that the effects of such support depend crucially on which stage of development the South is in itself. More precisely, because the South is not homogeneous, the practical issue is which stage the particular Southern country under consideration finds itself. For example if it is the stage in which imitation exists alongside innovation, then subsidies should be directed at supporting Southern innovation. In the same vein support for Northern innovation can be counterproductive because it simply encourages Southern imitation which is a wasteful activity if innovation is possible in that region. However in the stage when the South specialises in the traditional good, no such problem occurs and support for Northern innovation is growth- and welfare-enhancing for the world. Currie *et al.* (1999) explore these issues in detail.

Patent protection needs to balance two potentially conflicting objectives: encouraging innovation in the North and facilitating development in the South. Whether these do in fact conflict depends on the Southern stage of development. At a low level of development more stringent patent protection enforces traditional activity in the South by preventing copying. On the other hand in the stage where innovation

and imitation co-exist it will encourage innovation at the expense of imitation and thus increase world growth. Similarly and more surprisingly Northern aid aimed at increasing human capital in the South can have an ambiguous effect on world growth. In stages I and II it encourages copying, discourages Northern innovation and slows down growth. However throughout we have treated the diffusion rate as exogenous whereas one would expect it to be positively related to Southern human capital. If this is the case then increasing the proportion of skilled workers in the South would also increase the North-South speed of knowledge transfer and see the progression into the imitation-innovation stage and finally the innovation stage, with positive effects on world growth. The one unambiguous benefit to both North and South arises from an increase in Southern efficiency across all sectors. Aid aimed at improving Southern infrastructure runs into none of the complexities arising from stronger patent protection or training the Southern workforce.

The review by Edwards (1993) of the literature relating trade orientation and economic performance appeals for a more rigorous conceptual framework that specifies the exact mechanisms at work. We have established two such mechanisms by which openness may, but not necessarily, increase world growth and welfare for both the North and South. The first is through specialisation in which trade sees the North devoting more resources to innovative R&D research. The second is through knowledge spillovers which enable the South to progress into higher stages of development. However this second channel has an ambiguous effect on world growth. In stage II where the South only copies, increased spillovers actually reduce the incentive to innovate in the North and long-term world growth falls; but as spillovers increase further the South enters stages where it begins to innovate and world growth increases. Despite this negative effect of a transition from phase I to phase II, all our trade equilibria yield higher growth rates and welfare than the autarky regime even when the South is in its copying stage of development. Thus we have provided theoretical underpinnings that provide support for policies aimed at increased economic integration of the world economy, especially if this is accompanied by the strengthening of International Property Rights which have the effect of encouraging innovation and discouraging copying in the South.

A The Full Steady State

In Southern stage III where both innovation and imitation occurs, the steady state described in section 3 takes the following form:

Product Shares, Rate of Copying:

$$\xi_c^S + \xi_i^S + \xi_i^N = 1. \tag{A.1}$$

$$c = g\xi_c^S/\xi_i^N, \tag{A.2}$$

Consumers:

$$r = \rho + g\theta(\sigma^{-1} - 1)(1 - \alpha)/\alpha. \tag{A.3}$$

$$(\xi_i^N X_c^S)/(\xi_c^S X_i^S) = \begin{cases} (C_m^S/C_m^N)^{-\varepsilon} & \text{(wide-gap)}, \\ \alpha^{-\varepsilon} & \text{(narrow-gap)}. \end{cases} \tag{A.4}$$

$$(\xi_i^N X_i^S)/(\xi_i^S X_i^N) = (C_m^S/C_m^N)^{-\varepsilon} \tag{A.5}$$

where $X_i^b = n_i^b x_i^b$ is total manufactured output of innovative goods in bloc b and $X_c^S = n_c^S x_c^S$ is similarly defined.

Financial Sector—the Arbitrage Conditions:

$$\text{Northern Innovation:} \qquad r + g + c = \frac{1-\alpha}{\alpha}\frac{C_m^N}{C_i^N}\frac{X_i^N}{\xi_i^N}, \tag{A.6}$$

$$\text{Southern Innovation:} \qquad r + g = \frac{1-\alpha}{\alpha}\frac{C_m^S}{C_i^S}\frac{kX_i^S}{\xi_i^S}, \tag{A.7}$$

$$\text{Southern Copying (narrow-gap):} \qquad r + g = \frac{C_m^N - C_m^S}{C_c^S}\frac{kX_c^S}{\xi_c^S},$$

$$\text{(wide-gap):} \qquad r + g = \frac{1-\alpha}{\alpha}\frac{C_m^S}{C_i^S}\frac{kX_c^S}{\xi_c^S}. \tag{A.8}$$

Labour Market:

$$\bar{L}^N = a_{Li}^N(1 - \xi_i^S)g + a_{Lm}^N X_i^N + a_{Lz}^N Z^N, \tag{A.9}$$

$$\bar{H}^N = a_{Hi}^N(1 - \xi_i^S)g + a_{Hm}^N X_i^N + a_{Hz}^N Z^N, \tag{A.10}$$

$$\bar{L}^S = a_{Lc}^S g\xi_c^S/k + a_{Li}^S g\xi_i^S/k + a_{Lm}^S(X_i^S + X_c^S) + a_{Lz}^S Z^S, \tag{A.11}$$

$$\bar{H}^S = a_{Hc}^S g\xi_c^S/k + a_{Hi}^S g\xi_i^S/k + a_{Hm}^S(X_i^S + X_c^S) + a_{Hz} Z^S. \tag{A.12}$$

Relative Knowledge Capital : $$k = K^S/K^N = 1 - \xi_i^N g/(g + \kappa), \tag{A.13}$$

The Traditional Sector : $$C_z^S = C_z^N. \tag{A.14}$$

Balanced Trade : $$Z^N + Z^S = \frac{1-\theta}{\theta C_z^S}\left[\frac{C_m^N X_i^N}{\alpha} + C_m^N X_c^S + \frac{C_m^S X_i^S}{\alpha}\right]. \tag{A.15}$$

Unit Cost and Factor Input Functions:

$$C_j^b = c_j^b (w_L^b)^{1-\gamma_j} (w_H^b)^{\gamma_j} = \gamma_j^{-1} w_H^b a_{Hj}^b = (1-\gamma_j)^{-1} w_L^b a_{Lj}^b;\ j = z, m, i, c. \tag{A.16}$$

Substituting for the unit cost functions and unit factor input functions from (A.16) gives 15 equations in 16 endogenous variables ξ_c^S, ξ_i^S, ξ_i^N, c, r, X_c^S, X_i^S, X_i^N, g, Z^N, Z^S, k, w_L^N, w_H^N, w_L^N and w_S^N. We can normalise one of the nominal variables and we choose the normalisation $w_L^N = 1$. Exogenous variables and parameters are discussed in Appendix B.

This gives Southern stage III. At the limit where copying ceases ($c \to 0$), but innovation remains ($X_i^S > 0$), as a result for instance of an increase in the exogenous parameter κ, the transition from stage III to stage IV occurs. At the limit where innovation ceases ($X_i^S \to 0$), but copying remains ($c > 0$) we have the transition from stage III to stage II. Then in stage II when copying disappears ($c \to 0$) the transition from phase II to I occurs. This completes the steady state for all four stages of Southern development. Numerical solution of this system use standard NAG library FORTRAN subroutines.

Welfare Calculations

Welfare for type l is obtained by substituting $(D_l^b)^\theta (Z_l^b)^{1-\theta} = E_l^b/P$ into (1). If we define $\bar{P} = p^\theta p_z^{1-\theta}$ where $p = [\xi_i^N (p^N)^{1-\varepsilon} + \xi_i^S (p_i^S)^{1-\varepsilon} + (\xi_c^S)^{1-\varepsilon}]^{1/(1-\varepsilon)}$, then $P = n^{\theta/(1-\varepsilon)}\bar{P}$. In the balanced-growth steady state, $\dot{n}/n = g$, or $n = n_0 e^{gt}$. After some manipulations, the steady-state welfare is calculated as:

$$U_l^b = \frac{1}{1-1/\sigma}\left[\frac{(E_l^b/\bar{P})^{1-1/\sigma} n_0^{\theta(1-1/\sigma)/(\varepsilon-1)}}{\rho - \theta(1-1/\sigma)g/(\varepsilon-1)} - \frac{1}{\rho}\right] \quad \sigma < 1; l = L, H. \tag{A.17}$$

B Calibration

For our simulations we need to calibrate exogenous variables or parameters: $\bar{H}$, ρ, α, σ, θ, efficiency (A's), distribution (γ's) and elasticity of substitution parameters in the cost functions in all the three sectors for both regions. We assume equal population sizes in the two regions and normalize $\bar{L}^b + \bar{H}_b = 1$, $b = N, S$ Microeconometric estimates suggest that CES production functions are close to Cobb-Douglas which we have assumed throughout the analysis. Both γ_m and γ_z are computed using *observed* factor input coefficients for Northern exports of high-tech and Southern exports of low-tech goods and data for factor prices w_H^b/w_L^b, $b = N, S$ (see Wood, 1994, Table 4.3, p. 130.). This leads to $\gamma_m = 0.13$ and $\gamma_z = 0.5$. For the efficiency parameters, we can define, without loss of generality, units of manufacturing and traditional output such that $A_m^N = A_z^N = A = 1$. Then put $A_m^S = A_z^S = A/\beta$, $A_c^S = A_i^N/a_c\beta$ interpreting R&D in the South under autarky as copying.

Empirical estimates of σ and α centre on $\sigma = 0.5$, $\alpha = 0.5$. We impose $\theta = 0.6$ and choose ρ, β, a_c, γ_i, A_i^N, $\bar{H}^N$, and $\bar{H}^S$ to calibrate an autarkic baseline with growth rates of 2.5% and 1% for North and South, and the real interest rate as 5%. From the steady state conditions under autarky, we obtain $\rho = 0.03$, $\gamma_i = 0.69$, $A_i^N = 0.43$, $\beta = 1.5$, $a_c = 0.7$, $\bar{H}^N = 0.25$, and $\bar{H}^S = 0.12$. This completes our calibration.

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