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## Openness, Intermediate Imports and Growth

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Kiel Working Paper No. 996

**Openness, Intermediate Imports and Growth**

by

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## **Openness, Intermediate Imports and Growth\***

Abstract:

We consider two channels via which foreign inputs into industrial production may lead to productivity effects. The first one concerns dynamic externalities between firms which share technical and organizational knowledge which is vital for the productivity growth of a particular industry. We show by which institutional mechanism firms are able to share proprietary knowledge which is of economic value for the competitor. An increase of the number of cooperating firms due to foreign direct investments leads to growth effects. The second channel of growth effects resulting from openness is derived from an increase of the imports of physical inputs due to a greater variety of inputs for final goods production.

Keywords: North-South trade, FDI, intermediate goods  
JEL classification: F12, F21, F23, O19, O31

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## **1 Theoretical background and related literature**

Recent studies confirm that sustained high growth rates of countries at a relatively early stage of development can be explained by high rates of knowledge acquisition. Openness of these economies plays a central role for greater access to superior technical and organisational knowledge. In particular, the availability of a greater variety and a higher quality of (initially) imported intermediate goods and the acquaintance with advanced production technologies and organisation account for the sustained higher levels of income growth. The uneven distribution of growth effects then reflects differences in the absorption capacity of technological and organisational knowledge across developing countries. Direct data on the effects of knowledge accumulation are inherently difficult to obtain and do not exist beyond individual microeconomic studies. Given the non-rivalry of technical and organisational knowledge (the use of one firm does not exclude the employment in another microeconomic unit) microeconomic studies might even be misleading in that they neglect the social character of knowledge accumulation. We therefore follow the suggestion of Lucas (1988) that urban centres are rather the natural unit of study in this respect. We combine this view with the results of urban economics on the relative

importance of knowledge spillovers between firms of the same industry (localisation effects) and firms belonging to different industries (urbanisation effects) for different individual industries (Henderson 1995a and 1995b,). These agglomeration effects are held to give rise to a structure of cities, where new industries tend to locate in relatively small highly specialised centres. As has recently been shown, city growth in highly developed countries is characterised by a stable rank size distribution (Eaton/Eckstein 1997 and Black/Henderson 1997). On the basis of this current research we interpret the differences of patterns of urbanisation to provide indirect evidence on the technological absorption capacity of developing countries.

In what follows we review the literature on the relationship between urbanisation and growth. We then discuss the role of foreign direct investment as a catalyst for closing "idea gaps" between developed and developing countries, i.e. its role as a mechanism of the transfer of technology.

### **1.1 Urbanisation and Growth**

The fact that economic activities and economic growth within countries are not evenly distributed in geographic space, even without the obstacles to

trade and factor mobility that occur between countries supports the presumption that the restriction of the analysis to aggregate, national entities might conceal important determinants of development. This has time and again been emphasised by those protagonists of the New Growth Theory who see technological development and human capital accumulation as social as opposed to individual endeavours (Lucas 1988; Basu 1993; Eaton and Eckstein 1997):

"But from the viewpoint of technology"...through which the average skill level of a group of people is assumed to affect the productivity of each individual within the group, a *national* economy is a completely arbitrary unit to consider."..

The effects of the average human capital "...have to do with the influences people have on the productivity of others, so the *scope* of such effects must have to do with the ways various groups of people interact, which may be affected by political boundaries but are certainly an entirely different matter conceptually." (Lucas 1988, p. 37)

"It seems to me that the 'force' we need to postulate account for the central role of cities in economic life is of exactly the same character as the 'external human capital' I have postulated as a force to account for certain features of aggregate development." (ibid., pp. 37-38)

The hypothesis of innovation based growth has a long tradition in historical research on urbanisation (Jacobs 1984; Bairoch 1988). It considers

the benefits of direct communication and as the basic reason for firms and workers to bear the higher costs of locating in agglomerations. The 'force' of the central role of cities postulated by Lucas has been formalised in the theory of circular cities as localisation or urbanisation economies. Localisation economies denote advantages from geographical clustering for firms of the same industry, while urbanisation effects denote advantages from locating in agglomerations with a large variety of industries.

Given the dramatic changes in communication technologies accompanied by a dramatic reduction in communication costs it has been argued that this will weaken the agglomeration effects and make cities largely obsolete. These speculations have recently been investigated by Gaspar and Glaeser (1996). They find that, although the importance of face-to-face communication may decrease given the new technical means of communication for some information categories, the transmission of complicated instructions with a high potential of misunderstanding require direct interaction in person. If the demand for the latter type of communication rises over time the need for face to face communication might even increase. They therefore reject the hypothesis of dramatic future decline of the importance of communication-related agglomerative forces.

## **1.2 Economic growth and the city system**

The analysis of the significance of the features of the system of cities for aggregate national growth centres around the question whether cities are sectorally specialised and whether new industries tend to locate in new cities which go through a cycle of growth to optimal city size similar to the growth process the mature cities have gone through on a different sectoral basis.

This type of analysis proceeds from the assumption of a 'representative city'. A theoretical justification for this type of analysis can be found in the models of urbanisation and growth of Henderson (1988). This model predicts that growth takes the form of the creation of new cities whose size converges to an optimum city size. New industries tend to locate in new cities, and in steady state new cities arise at the rate of population growth. As a consequence, all cities should be highly specialised and localisation effects should predominate.

Doubts on the universal validity of the implications of this theory have been raised by recent empirical studies on the development of the city systems and growth in the US (Black and Henderson 1997) and in France and Japan (Eaton and Eckstein 1997): They found that there is a stable size distribution of cities. That is, cities of different sizes showed equal growth

rates (parallel growth rather than divergent or convergent growth). Moreover, in France and Japan there was no entry of new cities at all. Black and Henderson found a much smaller percentage increase in the number of cities than the percentage increase of city sizes. The theoretical foundations of these findings are centred on the role of human capital accumulation for the growth of cities as suggested by Lucas (1988).

In the work of Black and Henderson (1997) the stable size distribution of cities is depicted as the distribution of completely specialised cities, producing either a (composite) consumption good or an intermediate good. The population distribution across cities is modelled as the result of the human capital investment (by conversion of the consumption good) and migration decisions of dynastic families.<sup>1</sup> Human capital is transferred from parents to newborns in the same city type only. Given that family members will generally earn different incomes by city type, there must generally be intra-family transfers across cities to maintain equality of per member consumption.

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<sup>1</sup> Migration is only possible at the beginning of a career. The strong assumptions on migration are defended to be required by the absence of markets for human capital and the 'no slavery' condition.

City formation and city size determination involves a trade-off within cities: Production in city occurs under localisation effects, i.e. efficiency of each firm is enhanced by having more firms of the same industry in a city. The increase of efficiency is the result of the communication between these firms on what inputs to buy from where, what products lines to emphasise and how to organise production (Fujita and Ogawa 1982, Kim 1988). Dynamically, the efficiency of larger cities will be increased by local human capital accumulation. All production takes place at the Central Business District, surrounded by a circle of residences where each resident lives on a lot of unit size, and commute to the CBD at a constant cost per unit distance. The equilibrium in the land market is characterised by a rent gradient, declining linearly from the center to the city edge where rents are zero.

Black and Henderson's model requires that there are land developers, or autonomous local governments based mechanisms of self-organisation, that set up new cities. Otherwise cities will tend to be too large and too few in number. The relative advantage of governments of new cities in providing tax and expenditure policies limits the growth of mature cities.

In contrast, in the model of Eaton and Eckstein (1997) to explain the parallel growth of cities, knowledge accumulation is not completely localised. In fact, there is the possibility of knowledge spillovers (subject to

some losses) between cities. All cities produce the same kind of output but can nevertheless have different sizes. The average level of a city's human capital determines the total factor productivity, the positive effect of the average level of human capital endowment decreasing with the distance from the city center. Individuals inherit the human capital of their parents and can achieve a higher level of human capital by reducing labour supply (giving up the associated income) and investing in the acquisition human capital. Labour and land are the only factors of production. The decrease of the benefits with distance from the city center determines a declining land rent gradient. At the city boundaries urban land rents and land rents of alternative uses equalise.

The steady state growth of a city is characterised by the convergence of all residents' human capital levels to the city wide average. Individuals work a constant amount of time, total consumption and total income grow at a constant and common rate as do the wage rate and human capital. Whether per-capita-consumption grows or falls over time depends upon whether the effect of human capital accumulation overcompensates the congestion effects of population growth.

The whole system of cities is in steady state when all these conditions are met and in addition the cities' levels of human capital grow at a common

rate and there is no incentive to move. Migration decisions are taken individually, that is given the inherited human capital endowment, individuals can decide to move to a city with a higher endowment level, requiring an investment in the acquisition of human capital, or to move to a city with a lower average human capital level allowing for a lower level of time spent on increasing the personal human capital and enjoying the higher wage income. Moving down to a city with a lower level of per capita human capital is only of economic value if human capital is not entirely city specific.

The relationship between the level of human capital in each city and the common growth rate of human capital can be expressed as a system of linear differential equations. The larger the off-diagonal elements of the coefficient matrix of this system the greater are the knowledge spillovers between cities of human capital levels and different sizes.

Both the modeling approaches on the parallel growth of cities do not take account of the controversy around the relative merits of localization effects (efficiency increases due to the sectoral concentration within a city) versus urbanization effects (efficiency increases due to a large variety of sectors within one city). The recent empirical work on this controversy suggests that these agglomeration effects strongly influence the relationship

between the pattern of urbanization and growth on a national level and on the effects of a greater integration of national economies due to a dramatic reduction of communication costs.

Again following the suggestion of Lucas (1988) that cities provide natural laboratory to study the nature and extent of dynamic information externalities that are the driving force for technological innovation and hence economic growth dynamic localisation and urbanisation effects have been studied by Henderson et al. (1995a). Since these effects arise from both intended and unintended communications among economic agents, they are considered to be more readily observable in cities where communications are focused. As opposed to static localisation and urbanisation effects which are hypothesised to be more prevalent in smaller and medium size cities with industries such as textile, apparel, transport equipment, food-processing, pulp and paper etc. and larger cities with industries such as high-fashion apparel, upper-end publishing, and many business services, respectively, dynamic externalities deal with the role of prior information accumulation in the local area for current productivity and employment. These activities are seen to be fostered by a history of interactions and cultivated long-term relationships, which lead to a build-up of knowledge available to firms just in a local area. The dynamic economies

that derive from a build-up of knowledge associated with ongoing communications among local firms in the same industry are called Marshall-Arrow-Romer economies, as localisation due to local communications within the own industry has been emphasised by these authors. The dynamic economies that go back to the build-up of knowledge associated with historical diversity are called Jacobs production economies, as the hypothesis of diversity favouring knowledge spillovers between firms in the same local area has been emphasised by Jane Jacobs.

Using data on the growth of large industries in 170 US. cities between 1956 and 1987 Glaeser et al. (1992) found that local competition and urban variety, but not regional specialisation encourage employment growth in industries. Their interpretation of the evidence is that intra-industry knowledge spillovers are less important for growth than spillovers across industries, particularly in the case of rather mature industries.<sup>1</sup>

These findings are opposed to those of Henderson et al. (1995a), and Henderson (1995b). Using data for eight manufacturing industries in 1970 and 1987 to test for and characterise dynamic production externalities in

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<sup>1</sup> This interpretation is qualified by the caveat that the particular period in U.S. history looked at is one in which traditional manufacturing industries have fared poorly because of import competition and the cities looked at are particularly mature cities.

cities they find evidence of both MAR and Jacobs effects. More specifically, for mature capital goods industries, there is evidence of MAR (localisation) effects but not of Jacobs effects. For new high tech industries, they observed the existence of both localisation and urbanisation effects. Their findings are consistent with notions of urban specialisation and product cycles, i.e. new industries prosper in large, diverse metropolitan areas, but with maturity, production decentralises to smaller, more specialised cities. For mature industries there is also a high degree of persistence in individual employment patterns across cities, fostered by both localisation effects and persistence in regional comparative advantage.

Using panel data for US county level employments Henderson (1995b) also found out that localisation effects appear to affect employment levels for five to six years afterwards whereas for diversity measures effects appear to persist for longer periods (beyond the sample period of the panel). Conditions four or more years ago typically have a greater direct impact than conditions last year, suggesting the presence of an ageing and transmission mechanism.

In the next subsection we review the literature that regards foreign direct investments as a crucial vehicle of closing "idea gaps" between developed and developing countries. The concept of the closing of "idea gaps" will be

central to our treatment of the role of foreign direct investments for the technological catching up of less developed economies.

### **1.3 Transfer of technology and "idea gaps"**

Romer's central hypothesis is that the bridging of 'idea gaps' which can be independent of 'object gaps' which manifest themselves in differences of capital intensities and endowments with human capital are central to the catching up of relatively poor economies:

"The notion of an idea gap directs attention to the patterns of interaction and communication between a developing country and the rest of the world. In particular, it suggests that multinational corporations can play a special role as the conduits that let productive ideas flow across national borders."..."the notion of an idea gap invoked"..."includes the concepts that some authors have in mind when they speak of a technology gap, but it is intended to suggest something quite broad. The word technology invokes images of manufacturing but most economic activity takes place outside of factories. Ideas include the innumerable insights about packaging, marketing, distribution, inventory control, payments systems, information systems, transactions processing, quality control, and worker motivation that are all used in the creation of economic value in a modern economy." Romer (1993a, p. 53

In Romer's writing technology is taken as a largely undefined primitive. It differs from objects like physical and human capital in that it can be replicated and transferred between nations without becoming unavailable in the home country. Technology defined in this way can be converted into a communicable form and sent to another place. Other channels of the transfer of ideas than foreign direct investments are joint ventures, marketing or license agreements or other forms of formal and informal cooperation on the use of a stock of knowledge. Indirect ways of transfer are the migration of skilled workers from advanced to developing countries and the education of workers and students from developing countries in industrialised countries.

A third possible hypothesis on the transfer of ideas is then that all countries have access to the same pool of knowledge while differences in technological progress are the result of different absorption capacities of individual countries (Romer 1993a; Parente and Prescott 1994). The absorption capacity is then a function of the endowment with human capital but also of the institutional structure, in particular the education system as well as the extent and the organisation of public and private research, a complex that has been coined the 'national innovation system' (Nelson

1993).<sup>1</sup> However, the theories on barriers to technology adoption are theories of relative income levels rather than growth rates. If the distribution of technology adoption barriers is constant over time, it follows that the cross-country distribution of per capita income shifts up over time with no variation of its range. This is what Parente and Prescott (1993) documented. This is, however, in contrast to the findings of Lichtenberg reported above that research and development efforts have an impact on growth rates.

The most general approach to the transfer of ideas is that of Eaton and Kortum (1997). They assume that the diffusion rates depend on the countries involved. That is, the rate of diffusion is specific to the source and destination of the innovation. If diffusion is more rapid within countries than between countries, then a country can achieve a higher relative level of productivity by doing more research. Faster adoption of technology also raises productivity. Productivity growth rates may be equalised over time since backward countries have a larger backlog of ideas to adopt.

The transfer of technology in the broad sense of Romer's theory of 'idea gaps' is crucially dependent on communication costs. The dramatic decrease of communication costs in the ongoing phase of globalisation therefore

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<sup>1</sup> As an early model of the technological absorption capacity of a country see Nelson and Phelps (1966).

support the hypothesis that the diffusion of ideas per se and in company with other forms of international economic relations should be central to the effects of globalisation.

Given the central role of communication for the transfer of ideas and given the fact that it is impossible to obtain *direct* data on the transmission of ideas we derive the hypothesis that the extent and the structure of urbanisation as well as the sectoral structure of cities provides *indirect* evidence on the absorption capacities of countries. We should then expect the benefits of globalisation to be the greater the higher the absorption capacity.

The objective of the theoretical part of this study consists of integrating the work on the city system for aggregate growth without neglecting the importance of the localisation and urbanisation effects. Moreover, and we start by doing that, we have to develop a theoretical understanding on the microeconomics of communication on the local level. Why do agents, which in many cases are competitors, trade information which could potentially weaken their competitive position? Why does this happen on a local level? The answer we give to these questions provide the basis for the development of a new model of city structure and aggregate growth that

accounts for diversity and does not require the complete specialisation of cities.

## **2 Communication externalities and urbanization**

### **2.1 Motivation**

There exists a substantial empirical literature documenting that firms cooperate in the exchange of technical and organisational know-how even if they compete on the product market. The theoretical literature, for example, on cooperation in R&D proceeds from the assumption that there are significant information leakages in the research process and/or that innovations can be easily imitated. In both cases the resulting disincentive on innovative activities is held responsible for a suboptimally low level of investment in R&D and a suboptimal accumulation of technical knowledge. (Johnson 1997; R. Allen 1996, Katz 1995). Even in the absence of undesired knowledge spillovers the innovator's inability to price discriminate perfectly will exclude that a firm selling information is able to appropriate all of the surplus generated by its licensing. This, in turn, implies a sale of knowledge at prices that lead to inefficiently low levels of utilisation by other firms (Katz 1986). The cooperation in sharing production related information with formal contracts specifying how the returns and the costs are shared are

then either discussed as a means to raise the degree of monopoly on the market for innovations or with respect to its welfare implications and the ensuing question whether the cooperation should be tolerated or promoted and supported by governments to internalise the research externalities. Whether policy measures are justified very much depends on the form of the competition on the product markets of the firms involved.

In contrast, our concern here is to look for an explanation for the cooperation of firms in sharing production related know how even if this could be perfectly protected. Some of the empirical literature suggests that the cooperation is based on the informal sharing of information during learning processes in networks between research departments of firms (von Hippel 1996,1996; R. Allen 1996; T. Allen et al. 1997). As von Hippel (1996, p. 292) notes:

"A firm's staff of engineers is responsible for obtaining or develop the know-how its firm needs when required know-how is not available in-house, an engineer typically cannot find what he needs in publications either. Much is very specialised and not published anywhere. he must either develop it himself or learn what he needs to know by talking to other specialists. Since in-house development can be time consuming an expensive, there can be a high incentive to seek the needed information from professional colleagues. And often, logically enough, engineers in firms which make similar products or use similar

processes are the people most likely to have that needed information. But are such colleagues willing to reveal their proprietary know-how to employees of rival firms? Interestingly, it appears that the answer is quite uniformly "yes" in at least one industry, and quite probably in many."

He reports in his study of US steel minimal firms that there was no explicit accounting of favours given and received but that the obligation to return a favour seemed to be strongly felt by the recipient. The supply of information is restricted to the network, according to the findings of von Hippel, in contrast to the interpretation of historical evidence by Robert Allen (1996, p.2) that all competitors were given free access to proprietary know-how.

In trying to explain the sharing of information that increases productivity it is, however, only shown that there is a prisoners' dilemma situation with potential gains from cooperation when the competitive advantage of obtaining information and withholding the own know-how is small relative to the payoff using the non-cooperative strategy (v. Hippel 1987, pp. 297-300). It does not explain why the informal trade of know-how occurs. In fact, not to disclose information is a dominant strategy independent of the value of the competitive advantage obtained by receiving information from a competitor and keeping the own knowledge secret. In our attempt to

explain why the informal exchange of proprietary knowledge occurs we draw on the literature which gives reason to the cooperative behaviour of sellers who have private information on the product quality and nevertheless refrain from providing low quality. "Community enforcement" provides a mechanism that induces sellers to behave cooperatively even when they meet particular buyers only infrequently and have a short-term incentive to cheat.

## **2.2 Related literature**

Klein and Leffler (1997) were the first to study the problem of credibly committing to offer high quality in a model where a continuum of buyers are randomly matched with several sellers and each one has a short term incentive to supply low quality at lower cost. The assumption that the observation of low quality choice of a seller is public information and the threat of a consequent boycott of the seller establish the community enforcement of cooperative behaviour in the form of selling always high quality products.

If the potential number of transacting agents is large and communication costs depend on geographical distances between locations of the trading partners the assumption of each defection being public information seems

particularly demanding. In other models it is assumed that players can only observe the actions taken in their own games and that there is an exogenous information transmission and processing mechanism revealing the types of agents (Okuno-Fujiwara and Postlewaite 1994, Kandori 1997a and Milgrom et al. 1997).

In a third class of models where players are unable to recognise their opponents in a large but finite population setting, sequential equilibria have been shown to exist on the basis of contagious strategies: All players who have been cheated once stop cooperating with any of the potential opponents, understanding that the whole society is in a process of switching to non-cooperative behaviour. In the sequential equilibrium the players stick to the cooperative strategy to avoid the general switch to the socially negative behaviour (Kandori 1997a and Ellison 1997). Community enforcement due to contagious strategies has the problematic consequence that cooperation is unstable in the sense that a single defection would render cooperation impossible for all other agents.

For the networking between firms we need to consider an informal information transmission mechanism which is imperfect in the sense that defection, withholding or giving incomplete or distorted information, cannot be always punished immediately and that knowledge on the

defection may only spread to part of the population of players. To model this type of community enforcement we draw on the model on word-of-mouth communication of Ahn and Suominen (1997).

### 2.3 The model

We assume that there is a large but finite number of  $M$  players. In each time period  $t = 1, 2, \dots$  two players are randomly matched to bilaterally exchange technical information which is of interest for the common research objectives. The quality of the information provided is not recognised immediately but becomes evident during ongoing production activities. Both have a short term interest to cheat: To withhold useful information while the opponent reports truthfully leads to an increase of the individual's instantaneous probability of making a productivity increasing discovery and avoids the catching up opportunities of the competitors. As, however, competitors are able to detect useless or misleading information, private reputations evolve. This follows from the fact that all members of local producer networks send and receive signals on the opponent's behaviour in the bilateral meetings. If these signals are correct, a sequential equilibrium exists where all members of the network report truthfully in every period.

More formally, there is a finite set of players  $\mathcal{I}^* = \{1, 2, \dots, M\}$ . Each individual trades know-how bilaterally and sends and receives signals on the reputation of other firms. The individuals are identified by their names or "locations". Player  $i$  is then referred to as the firm at location  $i$ .

Let  $\Theta$  be the set of all permutations of  $\mathcal{K}^*$ . In each period  $t$  a permutation  $\theta_t \in \Theta$  is chosen with uniform probability, independent of previous realisations. An individual  $\theta_t(i) \in \mathcal{K}^*$  is randomly matched with a player  $\theta_t(j) \in \mathcal{K}^*$  to play the following 2x2 information trade game.

**Table 1: Gains from the informal trade of know-how**

		Player i	
		disclose	withhold
Player j	disclose	1,1	-1,(1+g)
	withhold	(1+g),-1	0,0

If the players cooperate they receive a payoff of 1 each, as both enhance their production possibilities. If both players refuse to communicate there is no change compared to the situation of the isolated accumulation of knowledge.  $(1+g)$  is the value of continuing one more round receiving information but without revealing the own know how and  $1$  the loss resulting from the disclosure of revealing information while being cheated by the opponent. To receive information while refusing to offer a return

increases the player's instantaneous probability of having a competitive advantage as it avoids imitation possibilities of the competitors. A firm which reports truthfully and is cheated weakens its position even relative to that of not communicating at all. Consequently, the strategy pair {withhold, withhold} is the only Nash equilibrium of the information trade game. Without any further information, both parties would try gain superior technical know how in isolation.

The overall payoffs are, however, the discounted sums of payoffs from the repetition of the trade game. We assume that the individuals have a common discount factor  $\delta \in (0,1)$ . In each period  $t = 0,1,2,\dots$  there is preplay communication among the participants before the next round of know-how trade takes place. More precisely, this preplay communication proceeds as follows:

- a. Each firm is member of a network  $\mathcal{N}$  with  $A$  members. After each round of matching each player  $i$  recognises the identity of his own opponent  $\theta_t^{-1}(i)$  and the opponents  $\theta_t^{-1}(n)$  of all members  $n \in \mathcal{N}$  of the network. We assume that the quality of the information provided is not publicly observable but is discovered by the receiving party during the subsequent production process.

b. After the next round of matching and before the informal trading of know-how each player  $i$  sends a payoff-irrelevant signal on the quality of the reports of next round of know-how trading player  $i$  sends a payoff-irrelevant signal on the value of the report of  $\theta_t^{-1}(n)$  in past periods to the  $A$  members of the network. Thus each player receives one or more messages on the reputation of his current opponent if the latter is not unknown to all members of the network.

Let  $C = \{\gamma, \beta\}$  be the set of possible signals,  $\gamma$  meaning "good" and  $\beta$  meaning "bad".  $m_t^i(n)$  is then the message of firm  $i$  to the other firms  $n$  of the network and  $m_t(i) \in \{\gamma, \beta\}^A$  is the tuple of messages player  $i$  receives.

c. The firms who meet bilaterally play the above 2x2 simultaneous move game.

The quality of the information is denoted as  $\alpha_t(i) \in \{\gamma, \beta\}$ . The total information player  $i$  receives in each period can be written as  $\{\theta_t, m_t(i), \alpha_t(i)\}$ .  $H^t(i)$  denotes the set of all possible histories for a player up to but not including period  $t$ . By convention  $H^0(i) = \emptyset$ . An element  $h_t(i) \in H^t(i)$  includes the identity of all past matches, all past messages sent by player  $i$ , all past messages received, and all observations of the quality of reports to that date:

$$h_t(i) = \left( \theta_t, m_t(i), m_{\tau=0}^i, \alpha_{\tau}(i) \right)_{\tau=0}^{t-1}$$

The pure strategies for player  $j$  are then

$$\hat{m}_t^i: \Theta \times H^t(i) \rightarrow \{\gamma, \beta\}^N, \text{ and}$$

$$\hat{b}_t: \Theta \times H^t(i) \rightarrow \{\text{disclose, withhold}\}.$$

$\hat{m}_t^j(\theta_t, h^t(i))$  specifies the  $A$ -tuple of signals that buyer  $i$  with history  $h^t(i)$

sends to the other network members in period  $t$ .  $\hat{b}_t^j(\theta_t, h^t(i), m_t(i))$

specifies the choice of action of player  $i$  in period  $t$ . The behavioural

strategies of the agents are  $\left\{ \sigma_t^i \right\}_{t=0}^{\infty}$  which are sequences of the map

$$\hat{\beta}_t^i: \Theta \times H^t(j) \times \{\gamma, \beta\}^N \rightarrow \Delta\{\text{disclose, withhold}\}.$$

The equilibrium concept we apply is the sequential equilibrium. A sequential equilibrium requires that after any history a player's equilibrium strategy maximises the expected payoff, taken as given all other players' strategies and his beliefs about the signals and actions taken by other players in all previous periods. The beliefs have to be consistent with the equilibrium strategy profile and the private history. One sequential equilibrium is the refusal to provide know-how after any history. In what

follows we are interested in identifying a sequential equilibrium that supports a stable network of informal trades of technical know-how.

The analysis concentrates on a particular strategy profile which is called "unforgiving". With this strategy profile players meet and do trade information if they have never experienced or heard of a bad behaviour of the opponent. It requires them to deliver truthful information in know-how trade in period zero and in every period thereafter if a) they have always done so, and b) they have never acquired a bad status.

The concentration on the unforgiving strategy profiles can be justified on two grounds. First, the unforgiving strategy profile drastically facilitates the analysis. With other strategy profiles, to follow the strategy choice on the off-the-equilibrium paths is very complicated because incentives depend on beliefs about previous plays. The beliefs, in turn depend on the private histories. Strategies with less severe punishments, i.e. players forgiving after a certain number of periods, are fraught with the problem that the players do not know the first instance of a defection of the opponent and therefore cannot synchronise the last period of the punishment phase. Second, the unforgiving strategy profile provides the maximum punishment for a defector in the class of non-contagious strategy profiles. Therefore, the unforgiving strategy profile provides an important point of reference as it

identifies the minimum number of network members required to support the informal exchange of know-how.

Information about an agent's behaviour may spread personal experience and the pretrade communication of the network members. The effectiveness of that spread depends network size communicating on the opponents' past behaviour. The signals depend on the private histories of the agents who happen to be in a neighbourhood. Under the unforgiving behaviour of the players, player  $i$  pursues the following strategy profile in each round  $t = 0, 1, 2, \dots$  of bilateral encounters.

- a) In the first period disclose information truthfully. After that, if the outcome in opponent  $i$ 's past behaviour was cooperative, continue to report truthfully.
- b) Withhold information otherwise.
- c) If a player  $j$  has ever been cheated by the opponent  $\theta_t^{-1}(n)$  of player  $n$ ,  $j, n \in \mathcal{N}$ , he will signal  $\beta$ . If he has positive experience he will signal  $\gamma$ . Upon receiving a bad signal player  $n$  withholds information.
- d) A firm  $n$  cooperates otherwise.

At the beginning of each round  $t$  each player categorises the opponents into two disjoint status groups according to his private history  $H(j)$ . If he has been cheated by his current opponent or has received a signal  $\beta$  in the

preplay communication stage of round  $t$  the opponent gets a bad status. If a player has ever been refused information or he has played non-cooperatively himself with any of the opponents of the other members of the network he signals  $\beta$  to his fellow network members. He fully respects the messages he receives.

In each period two types of incentive compatibility constraints have to be met: First each agent must find it optimal to cooperate when everyone else is cooperating. Second, each agent must find it optimal to play non-cooperatively, once he has obtained a bad status.

To keep a player reporting honestly in the bilateral encounters the period gain from cheating  $g$  must be outweighed by the long-term loss resulting from the spread of the bad reputation among the fellow players. The spread of the bad reputation reduces the probability of being matched with another player that does not know about the bad status himself and belongs to a network of which no other member has a bad experience from trading with firm  $i$ . The second condition holds if a player who has once cheated cannot gain by switching to cooperation to slow down or turn around the process of the spread of the bad reputation.

More formally, the on the equilibrium path condition is

$$\sum_{t=0}^{\infty} \delta^t \geq (1+g) \sum_{t=0}^{M-A-2} \delta^t \frac{\binom{M-1-t}{A+1}}{\binom{M-1}{A+1}} \quad (1)$$

The quotient of binomial coefficients gives the number of groups with  $A+1$  members in the total population excluding player  $i$  and all those who have been cheated in the past divided by the number of groups of the network size  $(A+1)$  in the total population excluding player  $i$ . It indicates the probability of player  $i$  to be matched in period  $t$  with an opponent  $\theta_t^{-1}(i)$  who belongs to a network without anyone knowing about a bad status of  $i$ . In each period in which player  $i$  manages to realise the payoff  $(1+g)$  from playing non-cooperatively, one more player has learned about his bad status as it is assumed that incorrect information is discovered during the production process. After  $(M-A-2)$  periods it is impossible to obtain the payoff  $(1+g)$  from behaving non-cooperatively.

Polar cases of the inequality are those with a network size of zero and the maximal network size of  $M-2$ . Looking at these polar cases provides us with the following necessary conditions for the sequential equilibrium:

For  $A = 0$  the surplus of cooperating when all other firms play honestly is given by

$$\frac{1}{1-\delta} - \frac{(1+g)(M[1-\delta]-1)}{(M-1)(1-\delta)^2} = \frac{g(1+M(-1+\delta))+\delta}{(M-1)(1-\delta)^2} \quad (2)$$

A condition for the superiority of the cooperative strategy is

$$\delta \geq \frac{g(M-1)}{1+gM} \equiv \delta^* . \quad (3)$$

For discount factors larger than  $\delta^*$  cooperation is an equilibrium of the unforgiving strategy even without networking. The larger the total population the higher the discount factor will have to be. With  $M \rightarrow \infty$ ,  $\delta^*$  approaches 1. The smaller  $g$ , the larger the range of discount factors that allow for the sequential equilibrium.

For the largest possible network size  $A = M - 2$  we get as the surplus of always behaving cooperatively over always trying to cheat

$\frac{1}{1-\delta} - (1+g)$ , and as the equilibrium range for the discount factor

$$\delta \geq \frac{g}{1+g} \equiv \delta^{**} . \quad (4)$$

The cooperative sequential equilibrium exists even if bilateral informal trades may only take place infrequently. This is the case even with the quality of the matches being publicly unobservable and therefore the history of the trade being private information. Note that the meta-rule of the behaviour is non-contagious: The agents do not switch to non-cooperative behaviour altogether after having been cheated but only in those encounters with opponents that have a bad reputation.

**Proposition 1:** *Given an exogenous network of size  $A+1$  which communicates on the reputation of opponents in a random matching game of information trades, the strategy profile defined above is a sequential equilibrium under the following conditions:*

$$g \leq -1 + \frac{1}{(1-\delta)_2 F_1(1, 2 + (-1+x)M, 1-M, \delta)} = g^* \quad (5)$$

$$b_0 < \frac{1}{1+\delta - (1-\delta)g} \quad (6)$$

$$g \geq \frac{1 - (1-\delta)S}{1 - b_0 + (1-\delta)S} \equiv g^{**}, \text{ with} \quad (7)$$

$$S = \frac{(M-A-2)!(M-K-1)!}{(M-1)!(M-K-A-2)!} {}_2F_1(1, 2 + \ddot{A} - M, 1 + K - M, \delta) \quad (8)$$

$$g^{**} \leq g \leq g^* \quad (9)$$

**Proof:** As stated above the sequential equilibrium of reporting honestly in bilateral information trades depends on whether first, on the equilibrium path, it is profitable to cooperate in all rounds  $t = 0, 1, 2, 3, \dots$ . Second, once a player has obtained a bad reputation, it must be optimal to continue to behave non-cooperatively. Otherwise we could not exclude that a player who has successfully cheated some or all of the previous opponents is able to regain a good reputation, and can thus benefit from disturbing the cooperative sequential equilibrium (cf. the discussion in Kandori 1997a and Harrington (1994)).

Cooperating when all other players follow the equilibrium strategy of cooperating results in the payoff of 1 in each period. All agents assume an infinite sequence of encounters and therefore have an infinite time horizon. All have a discount factor of  $\delta$ . The total expected payoff of cooperation is then

$$T_C = \sum_{t=0}^{\infty} \delta^t \quad (10)$$

$T_C$  is an increasing function of the discount factor.

### 2.3.1 Networks with exogenous connections

The total number of agents be  $M$ . Contacts to other firms or agents arrive according to a Poisson process with an arrival rate such that there is exactly one encounter per period. By cheating a fellow player who plays honestly player  $i$  receives a period payoff of  $(1 + g)$ , with  $g$  denoting the non-negative percentage difference to the period payoff of cooperative behaviour. Any individual who has been cheated finds out that he received wrong or incomplete information during the research process before the beginning of the next period. If a player is matched with an opponent who has a bad reputation he refuses to trade productivity-relevant know-how. Therefore, the higher non-cooperative period payoff can only be realised if a player who has cheated before is matched with an opponent  $\theta_t^{-1}(i)$  who has not been disappointed before and belongs to a network of which no member knows about the bad status. If a player tries to cheat in all of the periods  $t$  the probability of realising  $(1 + g)$  is

$$b_t = \frac{\binom{M-1-t}{A+1}}{\binom{M-1}{A+1}} \quad (11)$$

The nominator of  $b_t$  indicates the number of networks of size  $A+1$  as subsets of the total of all agents excluding the agent  $i$  and those who have been cheated before. The denominator indicates the number of networks which could be formed out of the set of all firms excluding firm  $i$ .

After  $M-A-2$  cases of receiving the payoff  $(1+g)$  any opponent will refuse to cooperate and the firm is isolated. The total expected payoff of defecting permanently is then

$$T_D = (1+g) \sum_{t=0}^{M-A-2} \delta^t \frac{\binom{M-1-t}{A+1}}{\binom{M-1}{A+1}} \quad (12)$$

$T_D$  is a decreasing function of the network size as the decrease of denominator is greater than the decrease of the nominator with an increasing  $A$  and the number of periods in which  $(1+g)$  can be realised decreases. It is an increasing function of the discount factor.

Behaving cooperatively is a sequential equilibrium if

$$T_C \geq T_D, \text{ or}$$

$$\frac{1}{1-\delta} \geq (1+g) {}_2F_1(1, 2+A-M, 1-M, \delta) \quad (13)$$

with  ${}_2F_1$  denoting the hypergeometric function.

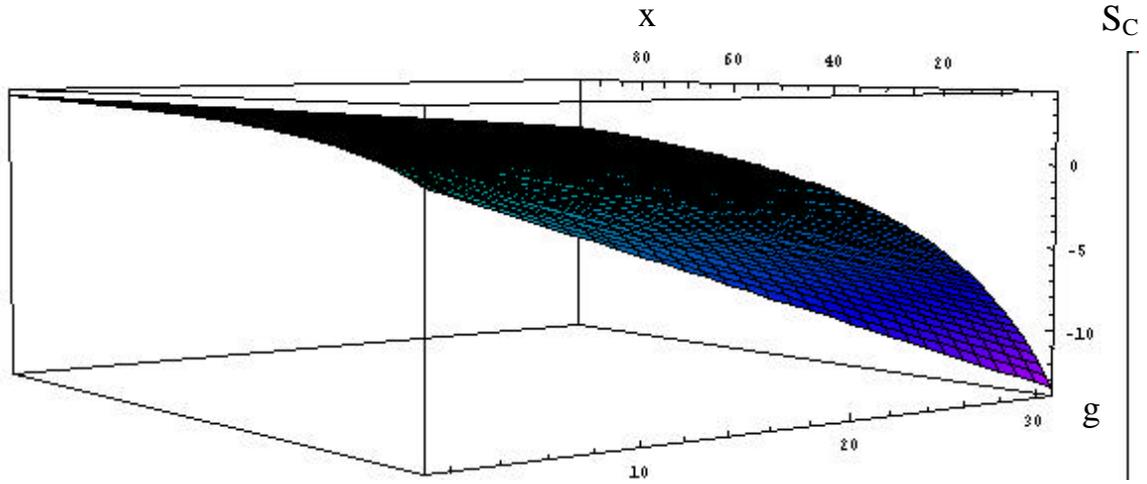
Taking A to be a percentage  $x$  of  $M$  with  $x = i/M$  and  $i$  being non-negative integers we obtain the expression  $S_C$  as the netgain of cooperating

$$S_C = \frac{1}{1-\delta} - (1+g) {}_2F_1(1, 2+M(-1+x), 1-M, \delta) \quad (14)$$

$S_C$  increases with the network size and increases with the discount factor as

$$\frac{\partial S_C}{\partial \delta} = \frac{1}{(1-\delta)^2} + \frac{1}{M-1} (1+g)(2-M(1-x)) {}_2F_1(2, 3+M(-1+x), 2-M, \delta) \quad (15)$$

**Figure 1: Surplus of Cooperation**



$$\delta \equiv 0.8, 0 \leq g \leq 3$$

The condition for the net gain of cooperative behaviour to be non-negative can be expressed as a maximal value of  $g$  as a function of  $x$  and  $\delta$ . Solving equation () for  $g$  we obtain

$$g \leq -1 + \frac{1}{(1-\delta) {}_2F_1(1, 2+(-1+x)M, 1-M, \delta)} \equiv g^* \quad (16)$$

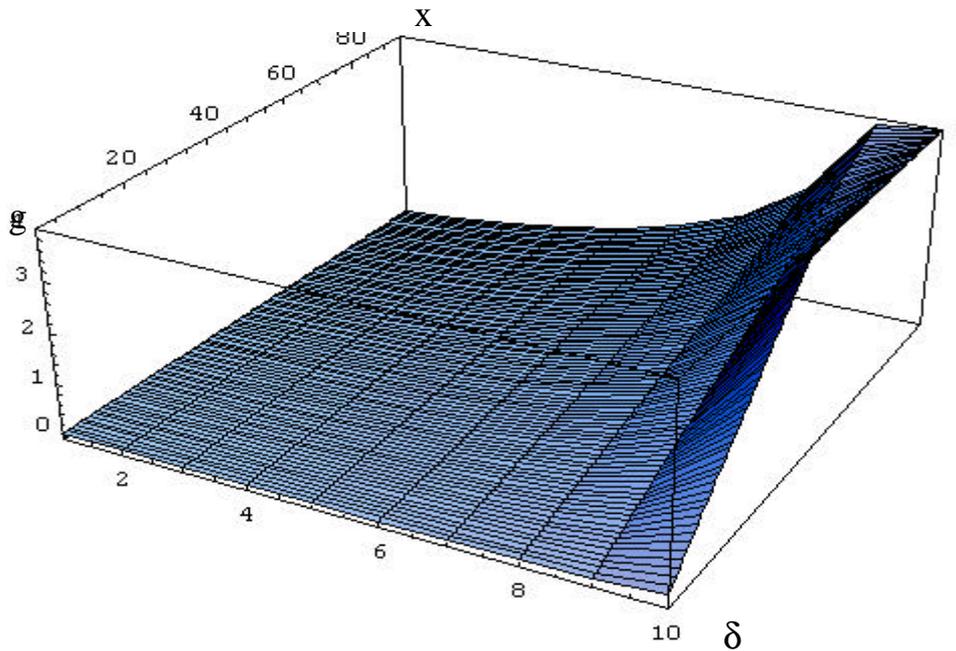
for  $\delta \in (0,1)$ , and  $0 \leq x \leq (M-A-2)/M$ .

For cooperation to be the social optimum and  $l$  being positive,  $g$  has to be larger than one. From this follows the condition on the hypergeometric function

$${}_2F_1(1, 2+(-1+x)M, 1-M, \delta) < \frac{1}{2(1-\delta)} \quad (17)$$

The maximal values for  $g$  which allow for the cooperative sequential equilibrium are shown in Figure 2.

**Figure 2: Maximal  $g$  for cooperative sequential equilibrium**



Next we identify the conditions under which an agent who has a bad reputation with some of the  $M$  researchers will continue to behave non-cooperatively. Assume that  $K$  players assign a bad status to researcher  $i$ . By the principle of dynamic programming it suffices to check that a one-time switch to cooperative behaviour is not profitable after any history of having obtained a bad status.

Cooperating in period  $t$  with  $K$  players knowing about agent  $i$ 's bad status and returning to non-cooperation afterwards results in the total expected payoff.

$$\begin{aligned}
T_{\text{DEV}} = & \frac{\binom{M-K-1}{A+1}}{\binom{M-1}{A+1}} - 1 \left[ 1 - \frac{\binom{M-K-1}{A+1}}{\binom{M-1}{A+1}} \right] + \\
& + (1+g) \sum_{t=0}^{M-K-A-2} \delta^{t+1} \frac{\binom{M-K-1-t}{A+1}}{\binom{M-1}{A+1}}
\end{aligned} \tag{18}$$

If player  $i$  instead continues to behave non-cooperatively in every period his total expected payoff is

$$T_{\text{NC}} = (1+g) \sum_{t=0}^{M-K-A-2} \delta^t \frac{\binom{M-K-1-t}{A+1}}{\binom{M-1}{A+1}} \tag{19}$$

If player  $i$  is to continue to defect in every period  $T_{\text{NC}}$  must be greater than  $T_{\text{DEV}}$ . To save notation we define

$$b_0 = \frac{\binom{M-K-1}{A+1}}{\binom{M-1}{A+1}}, S_0 = \sum_{t=0}^{M-K-A-2} \delta^t \frac{\binom{M-K-1-t}{A+1}}{\binom{M-1}{A+1}} \text{ and}$$

$$S_1 = \sum_{t=1}^{M-K-A-2} \delta^t \frac{\binom{M-K-1-t}{A+1}}{\binom{M-1}{A+1}}.$$

We then have

$$\begin{aligned} T_{\text{NC}} - T_{\text{DEV}} &= (1+g)(1-\delta)S_0 - b_0 + l(1-b_\beta) \\ &= (1+g)(1-\delta)S_1 - b_0 + l(1-b_\beta) + (1+g)(1-\delta)b_0 \geq 0 \end{aligned} \quad (20)$$

If the sum of the latter three terms of the above right hand side are positive  $T_{\text{NC}}$  is greater than  $T_{\text{DEV}}$  as the first term is necessarily positive. From this follows an upper bound for  $b_0$  and implicitly on the minimum network size:

$$b_0 \leq \frac{l}{1+\delta-(1-\delta)g} \quad (21)$$

Taking the smallest possible  $l$  we obtain an expression for the upper bound of  $b_0$  that holds for all admissible values of  $l$ :

$$b_0 \leq \frac{g-1}{(1+g)\delta-1}. \quad (22)$$

In general, the second incentive compatibility constraint for the cooperative sequential equilibrium is satisfied if

$$\begin{aligned} g &\geq \frac{1-(1-\delta)S}{1-b_0+(1-\delta)S} \equiv g^{**}, \text{ with} \\ S &= \frac{(M(1-x)-2)!(M-K-1)!}{(M-1)!(M(1-x)-K-2)!} {}_2F_1(1, 2+M(1-x), 1+K-M, \delta) \end{aligned} \quad (23)$$

$g^{**}$  is a decreasing function of  $S$ .  $S$ , in turn, is a decreasing function of  $K$ . To obtain a sufficient condition for the existence of the sequential equilibrium we have to determine the difference between  $g^*$  and  $g^{**}$  for the maximal  $K$ . The maximal possible  $K$  for which a player with a bad reputation might check the usefulness of switching to cooperative behaviour is  $K = M - A - 2$ . In this case the expression for  $g^{**}$  reduces to

$$g^{**}|_{K=M-A-2} = 1 + \frac{1-2\delta}{\delta - \binom{M-1}{A+1}}. \quad (24)$$

As  $g^{**}$  has to be larger than one and the denominator of the second term of the right hand side is always negative  $\delta$  must be larger than one half. The smallest denominator, and therefore the largest value for  $g^{**}$  is obtained for  $A = 1$  and for  $A = M - 3$ .

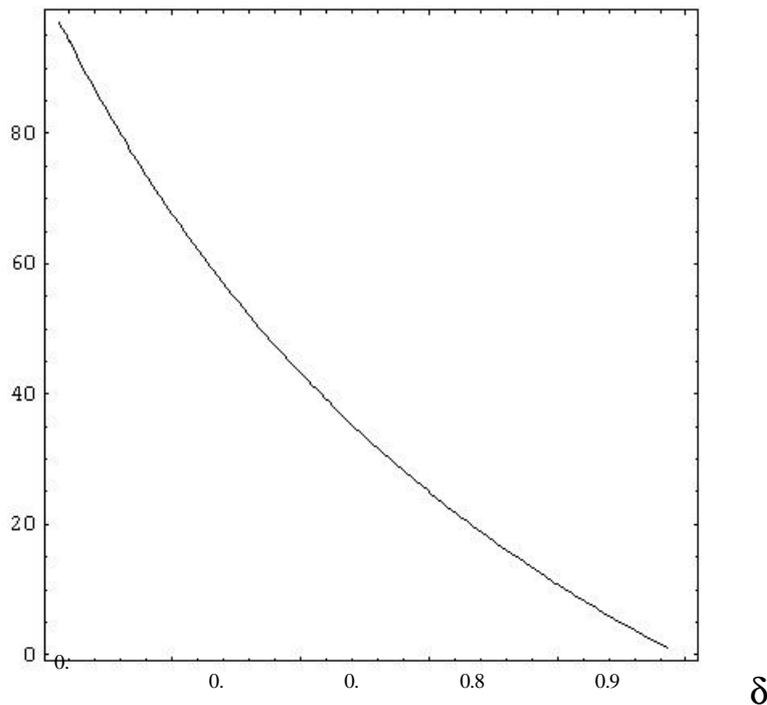
Taking both incentive compatibility constraints together we have

$$g^{**} \leq g \leq g^* \quad (25)$$

The condition  $(g^* - g^{**}) > 0$  gives the set of combinations of the relative network sizes and discount rates which are compatible with the sequential equilibrium. Projecting the combinations of relative network sizes and

discount rates with  $g^* - g^{**}$  onto the  $x$ - $\delta$ -plane and interpolating between these combinations we obtain the following graph

**Figure 2:** *Combinations of relative network sizes and discount factors compatible with the sequential equilibrium*



For all the combinations north-east of this contour the surplus of cooperative behaviour is positive and increasing in the relative network size with a decreasing stepsize.

If a member  $j$  of the network of the opponent  $\theta_t^{-1}(i)$  has been cheated by player  $i$  before he cannot gain by giving the wrong signal  $\gamma$  and should therefore signal the bad reputation of player  $i$ . If he has been matched with player  $i$  before and received useful information he should signal  $\gamma$ . Otherwise both of them would see themselves as having a bad reputation

and switch to non-cooperative behaviour in future encounters. If so this would reduce the expected payoff of the player who has given the wrong signal.

### ***2.3.2 Networks with endogenous connections***

We now relax the assumption that connections are exogenously given. Instead each firm has to invest to set up a network in the initial period. The costs of including another firm in the network depend on the geographical distance of a firm from the potential network member. The strategy profile set out in the previous section is modified in the following way:

- a) Each firm invests in setting up a network with other firms to communicate on the reputation of other firms in sharing informally productivity relevant information, expecting the other firms to behave according to the rules (b) to (e).
- b) In the first period disclose information truthfully. After that, if the outcome in opponent i's past behaviour was cooperative, continue to report truthfully.
- c) Withhold information otherwise.

- d) If a player  $j$  has ever been cheated by the opponent  $\theta_t^{-1}(n)$  of player  $n$ , where  $n \in \mathcal{V}_j$ , he will signal  $\beta$ . If he has positive experience he will signal  $\gamma$ . Upon receiving a bad signal player  $n$  withholds information.
- e) A firm  $n$  cooperates when it receives a positive signal or has good experience with firm  $\theta_t^{-1}(n)$ .

To identify the conditions under which endogenous networking occurs we first have to check whether there is an incentive to network at all. If cooperation were an equilibrium without networking the surplus of cooperative behaviour would have to be positive with a network size of zero. If the network size is zero the expression for the surplus of cooperation reduces to

$$S_C = \frac{1}{1-\delta} - \frac{(1+g)M(1-\delta)-1}{(M-1)(1-\delta)^2}$$

It is positive for

$$M > \frac{g+\delta}{g(1-\delta)} \equiv M^* \tag{26}$$

for  $\delta \in [0,1)$  and  $g > 1$ .

For  $M > M^*$  it is optimal to cheat in the informal trading of technical information if the network size is zero. As has been shown above the expected net gain of cooperation is a positive function of the network size.

**Proposition 2:** *If networking is costly and the costs of setting up a producers' network depend on the geographical distance between network members the network size is a function of the geographical density of producers. The size of the networks of a firm  $i$  is determined by the following conditions*

$$A^* = \arg \min_A \left[ cd_{\bar{j}\bar{j}+1} - cd_{i\bar{j}\bar{j}} \geq S_C(A+1) - S_C(A) \right] \text{ for } S_C > 0. \quad (27)$$

$$\sum_{j=1}^{\bar{j}} cd_{ij} \leq S_C(A^*) \quad (28)$$

**Proof:** If the costs of setting up a network of direct communication depends on geographical distances between the locations of firms the decision on the size of the network will be influenced by the density of the locations of firms. We denote the total costs of setting up a network of firm

$i$  as  $C_i = \sum_{j=1}^{\bar{j}} cd_{ij}$  with  $c$  being a constant and  $d_{ij}$  the distance between the

locations of firms  $i$  and  $j$ , with  $i, j \in \mathcal{N}^*$  and  $i \neq j$ . Each firm  $i$  orders the potential network members according to  $d_{ij}$ .  $C_i$  is then an increasing function, with increasing stepsizes if all the  $d_{ij}$  differ and/or with segments of equal step sizes if  $i$  has equal distances to more than one fellow player.

For networking to be profitable the minimum expected netgain of cooperative behaviour as a function of the network size must exceed the costs of networking. In expression ( ) indicating the total payoff of playing noncooperatively while the others follow the above strategy profile the exogenous network size  $A$  is replaced by the average network size of the firms another firm may be matched with. Given the conditions of Proposition 1 the optimal network size is determined by the condition

$$A^* = \arg \min_A \left[ cd_{i\bar{j}+1} - cd_{i\bar{j}} \geq S_C(A+1) - S_C(A) \right] \text{ for } S_C > 0.$$

If the strict inequality holds,  $\bar{j}$  is the most distant player included in the network. If the equality sign holds, player  $i$  randomises between including  $\bar{j}+1$  or only  $\bar{j}$ . Recall that  $S_C$  is an increasing function with decreasing step size. A second condition is that the total costs of networking do not exceed the expected surplus of cooperation with the optimal network size  $A^*$ :

$$\sum_{j=1}^{\bar{j}} c d_{ij} \leq S_C(A^*) \quad (29)$$

$d_{ij}$  then denotes the radius of the circle of the geographic area around the location of player  $i$  within which he will communicate on the reputation of the opponents whom network members are matched with to trade production relevant know how.

The larger the number of network members the smaller is the expected payoff of defecting and the larger is the expected surplus of playing cooperatively. Given that, according to conditions (27) and (28), the network size is the higher the higher the density of potential network members in geographical space, the firms have an incentive to locate in an agglomeration. As long as the netgain of cooperation exceeds the relocation costs, and possibly higher land rents in the agglomeration the firms will locate close to other producers.

## 2.4 Direct interaction and learning

We have investigated the microeconomics of an informal trade of information that is central to alleged localisation and urbanisation economies. These economies are often held to be based on direct communication between producers clustering in geographical space. The

analysis offers an explanation of why producers might share information which directly influences microeconomic production efficiency. We show that agglomerative tendencies exist even in the absence of information trade being associated with communication costs that depend on geographical distances between the communicating agents. Rather the observed cooperation between producers requires an institutional mechanism to prevent firms from seeking information without revealing their own know-how. Such shirking is avoided by setting up producers' networks whose member communicate on the reputation of firms they are matched with to trade production-relevant know how. The costs of setting up such a network depending on the distances between the network members provides an incentive to cluster in geographical space.

For the analysis of technology development and technology transfer between countries this has two consequences. First, the networking to avoid the prisoners' dilemma of information sharing may result in the growth of knowledge being localised. As a consequence the development of the national knowledge base is influenced by the location patterns of firms, as emphasised by the endogenous growth theory. Second, the existence of an institutional setting that favours information trade may be a precondition for foreign direct investments.

In the next subsection we develop the relationship between the local knowledge spillovers and international trade between developing and developed countries.

### **3 Urbanization, openness and technological development**

#### **3.1 Introduction**

As has been discussed in the introductory chapter there is overwhelming evidence that openness or the reduction of trade barriers in less developed countries (LDC's) has accelerated economic growth. As has been emphasised in the literature (see the review in Edwards 1989) these observations are inconsistent with neoclassical growth theory if aggregate income growth rates are interpreted as steady state growth rates. The latter are entirely determined by exogenous technical progress which is unrelated to measures of international economic policies. The endogenous growth models lack also lack a theoretical explanation of how openness affects the accumulation of technical and organisational knowledge.

Two main interpretations dominate in the case studies and descriptive work on the relationship between openness and growth in LDC's. The first one is that openness leads to greater specialisation which provides the

opportunity to exploit the dynamic scale economies associated with learning by doing (e.g. Meier 1989, pp 382 ff.). The second one consists of the assertion that the reduction of trade barriers allows imports that avoid growth hampering bottlenecks (e.g. Krueger 1983). The model we develop in this chapter builds on these arguments and tries to capture the idea that learning by doing is associated with information sharing by firms on the local level.

### **3.2 Sector-specific learning by doing and development bottlenecks**

We consider an economy that produces intermediate goods as well as consumption goods. Within each sector technological progress occurs through learning by doing.

The specialised production knowledge in each sector changes over time according to the equation

$$\dot{h}_i^* = \delta_i h_i^* u_i(t) \quad (30)$$

with  $h_i^*$  the knowledge base sector  $i$  has access to,  $u_i(t)$  the fraction of the total labor force employed in sector  $i$  and  $\delta_i$  a (constant) learning

coefficient.<sup>1</sup> To account for the spillovers between firms of the same sector and firms of different sectors the knowledge base  $h_i^*$  is not (necessarily) completely sector specific. if there are  $N$  sectors with sector specific human capital levels  $h_i$ , the knowledge base  $h_i^*$  which sector  $i$  draws upon is

$$h_i^* = \sum_{j=1}^N \alpha_{ij} h_j, \quad (31)$$

where  $\alpha_{ij} \geq 0$  indicate the contribution of sector  $j$  to the knowledge base of sector  $i$ . If a vector  $i$  has relatively larger values of  $\alpha_{ij}$  then  $i$  is a sector which uses production knowledge of other sectors with relative ease. If a sector  $j$  has relatively larger values of  $\alpha_{ij}$  its knowledge contributes more to the learning in sector  $i$ . To the extent that the matrix of  $\alpha$ 's is diagonal dominant, growth is generated primarily by sector specific factors. Less diagonal dominance implies more pooling of knowledge across sectors.

The knowledge is used in the individual sectors according to Ricardian production functions. For a given aggregate employment  $N$ , output  $x_i$  in

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<sup>1</sup> The equation contains the implicit assumption that knowledge spreads costlessly between firms. No individual firm has an incentive to increase employment in order to capture more technological progress.

sector  $i$  is the product of that sector's knowledge base and its employment level:

$$x_i(t) = h_i(t)u_i(t)N(t) \quad (32)$$

From equations (30) and (31) follows a growth rate of output per worker for sector  $i$  of  $\delta_i u_i$ . That learning by doing is not subject to diminishing returns is due to the fact that the LDC's face a continually and exogenously expanding technological frontier. The change of the technological frontier is assumed to be determined by R&D activities in developed economies. As long as a country does not catch up in its own technological development it can escape diminishing returns in knowledge accumulation.

In Lucas' growth model (1988) two industries produce consumption goods which are highly substitutable. Due to the high elasticity of substitution in consumption, that industry which is initially growing faster, and whose relative price is therefore falling, continually increases its share of output and employment. The initial size of the knowledge base determines initial relative growth rates. Learning by doing reinforces these effects and the economy ultimately specialises in only one good, even in autarky. The aggregate growth rate is equal to the  $\delta_i$  of the sector the economy specialises in. This result would also be obtained for a model of an

open economy, with the complication that the terms of trade of the country considered may improve or worsen, depending on which good the economy specialises in. That is, as long as we study only consumption goods sectors in a Lucas-type endogenous growth model, openness is irrelevant for the steady state growth rate.

In contrast to the growth theoretic literature, development studies have emphasised restrictions on growth which are due to an insufficient growth of the supply of intermediate goods. In particular, input substitution policies which were meant to relieve "dependence" on consumption goods imports led to shortages in the supply of imported intermediate goods and raw materials (see e.g. Krueger 1983). This experience of LDC's suggests low production elasticities of substitution in production: The growth process was constrained by the inability to specialise on those intermediate goods sectors that are growing only slowly.

Therefore, the model which will be presented in the next subsection has a range of intermediate goods in addition to consumption goods. As in the Lucas model the consumption elasticity of substitution is assumed to be high while production elasticities of substitution are assumed to be low. As a consequence, in autarky the model economy will specialise on the production of one consumption good but has also to produce the complete

set of intermediate goods. Aggregate growth then depends on the increases of productivity in all active sectors. Slow growing intermediate goods sectors then limit aggregate growth.

The stylised trade pattern implied by the assumptions on the model economy consists of LDC's imports of LDC's importing intermediate goods from DC's, exporting consumption goods in return.<sup>1</sup> As stated above, the technological development in the DC's is assumed to be quick enough such that the LDC's do not run into diminishing returns to learning. The growth of the world economy is assumed to be strong enough so that the DC's economies remain completely diversified. That is, its demand for consumption goods cannot be satisfied by the less developed countries alone. Consequently, prices for traded goods remain independent of the LDC's production activities. They are assumed to be price takers in the world markets.

Moving from autarky to free trade LDC's are then able to import those intermediate goods whose production is characterised by a relatively slow

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<sup>1</sup> There is scant empirical evidence on the trade between LDC's and DC's subdivided into intermediate goods and consumption goods (see however Harylyshyn and Civan (1985) and Quah and Rauch (1990, Appendix A)).

process of knowledge accumulation. Openness should therefore contribute to higher steady state growth rates.

### 3.3 The model

The economy is assumed to produce consumption goods as well as intermediate goods which in turn are inputs to the production of consumption goods.  $\mathcal{C}$  be the set of indices of consumption goods and  $\mathcal{I}$  the set of indices for the intermediate goods sectors. The sets are disjoint: No consumption good can be used as an intermediate good and no intermediate good can be consumed. All sectors employ workers who accumulate sector specific knowledge.  $u_j$  denotes the share of aggregate labour of sector  $j \in \mathcal{C} \cup \mathcal{I}$  and the per worker level of production relevant knowledge in that sector is indicated by  $h_j$ .

The preferences of the representative consumer of the economy  $k$  are given by

$$u^k = \left[ \sum_{m \in X} \gamma_m^k c_m^\rho \right]^{\frac{1}{\rho}}, 0 < \rho < 1 \quad (33)$$

where  $c_m$  is the consumption of good  $m$ . As in the Lucas-type growth models the elasticity of substitution  $\sigma = (1 - \rho)^{-1}$  is a constant exceeding one.

The consumption goods and intermediate goods sectors use different production technologies. The production of intermediate goods requires only labour inputs. Technology is assumed to be linear and identical across economies:

$$x_n = h_n u_n N, \text{ for all } n \in \mathcal{I} \quad (34)$$

Land and labour are used in fixed proportions.

$$x_n = \xi(2\pi d)$$

The production of consumption goods requires as inputs intermediate goods, land and labour, and technology differs across economies by a Ricardian technological efficiency coefficient. Economy  $k$  then produces consumption goods according to the CES function

$$x_m = A_m^k d^{-e} \left[ \theta_1 \sum_{n \in \mathcal{I}} x_{nm}^\varphi + \theta_2 (2\pi d)^\varphi + \theta_3 (h_m u_m N)^\varphi \right]^{\frac{1}{\varphi}}, \text{ with } 0 < \theta < 1,$$

$$\varphi < 0. \quad (35)$$

$x_{nm}$  indicate the quantity of intermediate good  $n$  used in the production of consumption good  $m$ . Productivity is decreasing with increasing distance  $d$  from the city center.

To (35) corresponds a cost function

$$c(p_n, r, w; x_m) =$$

$$x_m A_m^{-1} d^{\frac{e-\varphi}{\varphi}} \left( \theta_1^{1-\varphi} \sum_n p_n^{\frac{\varphi}{\varphi-1}} + \theta_2^{1-\varphi} r^{\frac{\varphi}{\varphi-1}} + \theta_3^{1-\varphi} \left( \frac{w}{h_m} \right)^{\frac{\varphi}{\varphi-1}} \right)^{\frac{\varphi-1}{\varphi}}$$

for all  $m \in \mathcal{L}$

(36)

Let  $p_j$  denote the price for good  $j$  in  $\mathcal{L} \cup \mathcal{H}$ , and  $w$  the wage rate for labor. Under perfect competition output is determined by the zero profit condition.

$$p_m =$$

$$A_m^{-1} d^{\frac{e-\varphi}{\varphi}} \left( \theta_1^{1-\varphi} \sum_n p_n^{\frac{\varphi}{\varphi-1}} + \theta_2^{1-\varphi} r_d^{\frac{\varphi}{\varphi-1}} + \theta_3^{1-\varphi} \left( \frac{w}{h_m} \right)^{\frac{\varphi}{\varphi-1}} \right)^{\frac{\varphi-1}{\varphi}}, \text{ for all}$$

$m \in \mathcal{L}$

(37)

Applying Shephard's Lemma to the right hand side of (38) we obtain the derived demand functions for labor, intermediate goods and land

$$u_m N = x_m \left[ A_m^k \right]^{\frac{\varphi}{1-\varphi}} d^{\frac{e-\varphi}{\varphi-1}} p_m^{\frac{1}{1-\varphi}} h_m^{\frac{\varphi}{1-\varphi}} \left( \frac{\theta_3}{w} \right)^{\frac{1}{1-\varphi}} \quad (39)$$

$$x_{nm} = x_m \left[ A_m^k \right]^{\frac{\varphi}{1-\varphi}} d^{\frac{e-\varphi}{\varphi-1}} p_m^{\frac{1}{1-\varphi}} \left( \frac{\theta_1}{p_n} \right)^{\frac{1}{1-\varphi}} \quad (40)$$

$$2\pi d = x_m \left[ A_m^k \right]^{\frac{\varphi}{1-\varphi}} d^{\frac{e-\varphi}{\varphi-1}} p_m^{\frac{1}{1-\varphi}} \left( \frac{\theta_2}{r} \right)^{\frac{1}{1-\varphi}} \quad (41)$$

The land rent corresponding to the above demand equations is

$$r_d = \theta_2^{\frac{\varphi}{1-\varphi}} \left( p_m^{\frac{\varphi}{1-\varphi}} A_m^{\frac{\varphi}{1-\varphi}} d^{\frac{e-\varphi}{\varphi-1}} - \theta_1^{\frac{1}{1-\varphi}} \sum_n p_n^{\frac{\varphi}{1-\varphi}} - \theta_3^{\frac{1}{1-\varphi}} w^{\frac{\varphi}{1-\varphi}} \right)^{\frac{\varphi-1}{\varphi}} \quad (42)$$

The explicit term for  $d$  and the fact that  $p_m$  decreases with an increasing  $d$  imply that the land rent is decreasing with distance from the city center.

We assume that it costs  $r^*$  to use land for urban purposes which is constant across time and cities. The distance from the city center at which  $r_d$  has fallen to  $r^*$  establishes the city limits  $D$ . Substituting in the expression of the equilibrium wage we obtain a condition which relates the radius of the city  $D$  to the wage  $w$  and the level of human capital.

$$w = h_m \theta_3^\varphi \left[ \left( p_m A_m^k \right)^{\frac{\varphi}{\varphi-1}} D^{\frac{e-\varphi}{1-\varphi}} - \theta_1^{\frac{1}{1-\varphi}} \sum p_n^{\varphi-1} - \theta_2^{\frac{1}{1-\varphi}} r_d^{\varphi-1} \right]^{\frac{\varphi-1}{\varphi}} \quad (43)$$

Hence a city's wage increases with the level of human capital in the consumption sector but falls with the city's radius. Substituting this equation in (43) and integrating over all urban locations we obtain an expression for the urban labour force in terms of the city radius  $D$  and the level of the knowledge base.

Integrating the land rent from the city center to the city limits we obtain the total return to land of a city at time  $t$ , net of the costs of urban services  $r\pi D^2$ .

We now turn to the dynamics of the intermediate goods sectors, the dynamics of the consumption goods sectors and the dynamics of intermediate relative consumption goods sectors:

From the production function of the intermediate goods sectors we have for the total labour demand of the intermediate good  $m$ :

$$u_n N = h_n^{-1} \sum_m x_{nm} = h_n^{-1} \left( \frac{\theta_1}{p_n} \right)^{\frac{1}{1-\varphi}} d^{\frac{e-\varphi}{\varphi-1}} \sum_m x_m \left[ A_m^k \right]^{\frac{\varphi}{1-\varphi}} p_m^{\frac{1}{1-\varphi}} \quad (44)$$

Thus, for any two intermediate goods,  $j$  and  $n$  in  $\mathfrak{S}$ , the ratio of labour inputs is

$$\frac{u_n}{u_j} = \left( \frac{h_n}{h_j} \right)^{-1} \left( \frac{p_n}{p_j} \right)^{\frac{1}{\phi-1}} \quad (45)$$

Given the learning equation (31), the ratio  $h_n/h_j$  cannot jump but instead evolves as a function of employment in the two sectors. Using the zero profit condition for all active intermediate goods  $p_n = \xi^{-1}r_d + h_n^{-1}w$  the price ratio equals

$$\frac{p_n}{p_j} = \frac{\xi^{-1}r_d + h_n^{-1}w}{\xi^{-1}r_d + h_j^{-1}w} \quad (46)$$

Combining these facts we obtain for the dynamics of the knowledge base across intermediate goods

$$\frac{\dot{h}_n/h_n}{\dot{h}_j/h_j} = \frac{\delta_n}{\delta_j} \left( \frac{h_n}{h_j} \right)^{-1} \left( \frac{\xi^{-1}r_d + h_n^{-1}w}{\xi^{-1}r_d + h_j^{-1}w} \right)^{\frac{1}{\phi-1}} \quad (47)$$

Defining

$$\phi(h_n, h_j) = \left( \frac{h_n}{h_j} \right)^{-1} \left( \frac{\xi^{-1}r_d + h_n^{-1}w}{\xi^{-1}r_d + h_j^{-1}w} \right)^{\frac{1}{\phi-1}},$$

we can show by fixing  $h_j$  and differentiating  $\log \phi$  with respect to  $h_n$  that the intermediate goods sector is stable, i.e. the derivative is negative. That is, all intermediate goods sectors remain active in autarky equilibrium. This follows from the fact that the intermediate good price ratio is decreasing in the corresponding ratio of sectoral knowledge bases. If  $h_n$  increases, this has a negative direct impact on employment. The relative price reduction as a consequence of the increased knowledge base and the substitution effect in the use of intermediate goods cannot compensate for the employment reducing direct effect because of the low elasticity of substitution in production. As the increase of the sectoral knowledge base varies inversely with the employment share of that sector, the relative growth in the sector with the greater human capital stock decreases. This leads to stabilisation and the fact that the sectors with a relatively small initial knowledge base remain active.

Turning to the consumption sector we obtain as the ratio of labor shares, for any two subsectors  $m$  and  $i$  of  $\bullet^*$ :

$$\frac{u_m}{u_i} = \left( \frac{A_m^k}{A_i^k} \right)^{\frac{\phi}{1-\phi}} \left( \frac{p_m}{p_i} \right)^{\frac{1}{1-\phi}} \left( \frac{h_m}{h_i} \right)^{\frac{\phi}{1-\phi}} \frac{x_m}{x_i} \quad (48)$$

In autarky equilibrium we have  $x_m/x_i = c_m/c_i$ . In the household equilibrium we have

$$\frac{c_m}{c_i} = \left( \frac{p_m}{p_i} \right)^{\frac{1}{\rho-1}} \left( \frac{\gamma_m^k}{\gamma_i^k} \right)^{\frac{1}{1-\rho}} \quad (49)$$

We then have for the ratio of labour shares of any two consumption goods

$$\frac{u_m}{u_i} = \left( \frac{A_m^k}{A_i^k} \right)^{\frac{\phi}{1-\phi}} \left( \frac{p_m}{p_i} \right)^{\frac{1}{1-\phi} + \frac{1}{\rho-1}} \left( \frac{\gamma_m^k}{\gamma_i^k} \right)^{\frac{1}{1-\rho}} \left( \frac{h_m}{h_i} \right)^{\frac{\phi}{1-\phi}} \quad (50)$$

The left hand side indicates the growth rate of the knowledge base in sector  $m$  relative to that of sector  $i$ . The exponent of the ratio of the knowledge bases being negative it is a stabilising factor: If the knowledge base  $h_m$  exceeds  $h_i$  we have a faster growth in sector  $i$  and thus a self-correcting

mechanism. However, as we will show the ratio  $\left( \frac{p_m}{p_i} \right)^{\frac{1}{1-\phi} + \frac{1}{\rho-1}}$  is

increasing in the ratio of knowledge bases for sufficiently large values of  $\rho$ .

In case the latter effect dominates, the model economy will specialise in whichever sector happens to have its specialised technology growing more rapidly. The mechanics by which this happens is as follows: as  $h_m$  increases, the price of consumption good  $m$  falls. With a high enough elasticity of

substitution in consumption, both equilibrium output and employment in that sector increase, which causes an even faster increase in the knowledge base of sector  $m$ .

More formally we have from the cost equalling price conditions we have

$$\left(\frac{p_m}{p_i}\right)^{\frac{1}{1-\phi} + \frac{1}{\rho-1}} = \left(\frac{A_m^k}{A_i^k}\right)^{\frac{1}{\phi-1} + \frac{1}{1-\rho}} \left( \frac{\left( \theta_1^{1-\phi} \sum_n p_n^{\frac{\phi}{\phi-1}} + \theta_2^{1-\phi} r_d^{\frac{\phi}{\phi-1}} + \theta_3^{1-\phi} \left(\frac{w}{h_m}\right)^{\frac{\phi}{\phi-1}} \right)^{\frac{\phi-1}{\phi}}}{\left( \theta_1^{1-\phi} \sum_n p_n^{\frac{\phi}{\phi-1}} + \theta_2^{1-\phi} r_d^{\frac{\phi}{\phi-1}} + \theta_3^{1-\phi} \left(\frac{w}{h_i}\right)^{\frac{\phi}{\phi-1}} \right)^{\frac{\phi-1}{\phi}}} \right)^{\frac{1}{1-\phi} + \frac{1}{\rho-1}}$$

Differentiating the logarithm of the second term on the right hand side with respect to  $h_m$  we obtain an expression which is positive for values of  $\frac{1}{1-\rho}$  large enough, in case the ratios between the knowledge base of the dominant consumption sector and all of the intermediate goods sectors remain bounded.

To show that these ratios of knowledge bases remain bounded we have to calculate the ratios of labour shares of the specialised consumption good

and all of the intermediate goods sectors. It can be shown that the resulting equation gives a stable system in human capital stocks across the specialised consumption good and all intermediate inputs.

The dynamics of the relative price of the specialised consumption good is decreasing in the total factor productivity and the learning coefficient of the consumption good. It is relatively more expensive in the steady state if either the economy is absolutely less efficient at producing it or the good itself is a slow learning good.

In autarky the sectoral knowledge bases in the active sectors of this model economy have a common growth rate  $g$  given by

$$g = \frac{\dot{h}_m}{h_m} = u_m \delta_m = u_n \delta_n, \text{ for all } n \in \mathfrak{N} \quad (51)$$

Under full employment we must have

$$u_m + \sum_n u_n = 1, \text{ or}$$

$$g \left( \delta_m^{-1} + \sum_n \delta_n^{-1} \right) = 1, \text{ which implies}$$

$$g = \left( \delta_m^{-1} + \sum_n \delta_n^{-1} \right)^{-1} \quad (52)$$

One consequence of the model is that countries which otherwise appear identical differ in their growth rates. Whether or not economies have the same growth rates depends on which consumption good the economy specialises, or rather whether their total factor productivities and/or learning coefficients differ.

If the economy could just specialise on the consumption good the growth rate would be identical the learning coefficient of the consumption good sector. The fact that it has to produce intermediate goods reduces the aggregate growth rate:

$$\left( \delta_m^{-1} + \sum_n \delta_n^{-1} \right)^{-1} < \left( \delta_m^{-1} \right)^{-1} = \delta_m. \quad (53)$$

the fall in the steady state growth rate occurs regardless of the relative values of the learning coefficients in the consumption and intermediate goods sectors. The reason for this result is that the balanced growth according to (53) assigns more labour to the slow learning sectors in terms of the learning coefficient. This in turn is the reason why the aggregate growth rate is reduced in the no-trade situation.

If a less developed country opens up and thereby gains the opportunity to import intermediate goods which constitute bottlenecks because of the small learning coefficients. For the extreme case that the economy specialises on the export of the consumption good the LDC can bypass the production bottlenecks created by the slow growing subsectors and increase its growth rate to  $\delta_m$ .

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