Consumption complementarities, monopolies, and coordination

P. Frijters

Abstract

Price-coordination and investment coordination are analyzed in a monopolistic multi-sector general equilibrium model with consumption complementarities.

Possible solutions to the investment coordination problem are consistent with historical examples of government intervention in investment, the different roles of banking sectors in different countries, and the effect of optimism on the development of new sectors.

Price coordination within sectors between monopolists of complementary intermediaries lowers prices and increases welfare because the competition between the final goods of different sectors then becomes the paramount concern of each monopolist. With no price coordination, each monopolist sets infinite prices as the effect of price increases on demand is shared by all other intermediary monopolists due to the complementarities.

1 Introduction

Each island in the fictitious islandgroup of Tawahu provides a holidays for tourists. One island offers crayfishing and deep sea diving, another has high waves suitable for surfing, yet another provides a sandy beach. Each island hence provides a unique holiday experience which is not perfectly substitutable. On each island there is one airport operated by one airliner, one road exploited by one taxi-company, one hotel, and one leisure facility. Each holiday needs one of each four services to be complete.

Consider first the investment problem on each island: a prospective airliner will only build an airport if he expects someone else to build the road and another to build the hotel. The prospective hotel owner will only build a hotel if he expects someone else to provide a leisure activity. Coordinating these investments may be done by a local government, a bank, or a very large corporation who sets up all facilities at once but pays overhead costs due to being large. If it is not possible for one investor to put up all facilities then the more diverse the investors needed, the harder the coordination will be, which may be a reason why on some islands there are still no foreign investors developing the island even though it is known that all facilities are technically possible.

Consider next the price problem of each service provider on each island: if a service provider, say the hotel manager, increases prices, this will reduce the number of customers for everyone else on the island as well. In the absence of price coordination on an island, this will lead to high prices and few tourists. If all services on one island coordinate however, they can attract customers from

other islands and increase profits by lowering prices. As a result, coordination between services on an island seems a likely outcome. The effect when there is price coordination on each island however is that there are lower prices and more customers on all islands and, as we shall see, lower profits for each individual service provider. If however all service providers on all islands coordinate with everyone else, prices will again be very high and there will be few customers on all islands. Hence the no-coordination and complete-coordination cases lead to similar outcomes.

Consider finally the discovery of a new island. Investments are uncertain: it is not known beforehand whether the soil is suitable for an airport or a road; it is not known whether the climate would allow a hotel or whether there are enjoyable leisure activities. The first one to invest (an airliner) will have least security about the feasibility of the final product (a pleasurable holiday). Once the airport, the road, and the hotel are found to be feasible and built however, the provider of the last facility to be discovered (leisure) will have the security that if he finds a leisure activity, a final product is feasible. As a result, the number of leisure activity operators trying to find a leisure activity will be large as each competes for the leisure monopoly if there is a leisure activity. Due to increasing returns to scale, there will only remain one leisure activity operator if it is discovered. Hence, even assuming coordination is possible, there is a growing level of investment with each discovered facility on the island and the amount of investment will be inefficient due to the monopoly once discovered.

In this paper the arguments contained in the story of the islandgroup of

Tawahu are formalized in a simple multi-sector monopolistic one-period general equilibrium model with consumption complementarities[1]. The main difference with previous studies (e.g. Cooper and John (1988), Lin (1995) and Krugman and Venables (1995)), where complementarities are modelled as demand linkages between sectors, is that the complementarities in this paper are only assumed to exist within sectors and the monopolies are natural.

The model is presented in the second section. The investment and pricing coordination issues are discussed in the third section. The effect of complementarities on investment during innovation periods is discussed in the fourth section. In the fifth section the welfare implications are discussed and some comments are made on the model's implications for international trade and endogenous growth. The final section concludes.

2 The model

There are n+1 sectors. In the zero sector, labour and capital is combined in a decreasing returns to scale technology:

$$Y_0 = L_0^{\alpha} K_0^{\beta} \text{ with } \alpha + \beta < 1$$

where L_0 equals labour employed in sector 0 and K_0 equals the amount of capital employed in sector 0. The total amount of labour and capital available

[1] For an overview of the literature on complementarities, known also as demand linkages or demand externalities, see Miyagawa (1993) or Milgrom and Roberts (1995). For empirical support for the importance of complementarities, see e.g. Bartelsman et al. (1994), Cooper and Haltiwanger (1996), Cooper and Johri (1997), and Miyagawa (1996).

equals K and L which is fixed as only a one period model is used.

If we interpret this zero sector as the agricultural sector, an assumption of decreasing returns to scale indeed seems to fit known productivity profiles of this sector. A different interpretation of the zero sector is that it denotes the informal or "grey" sector.

For the i>0 sector, called the industrial sectors, each sector subdivides into k intermediary producers who combine a fixed amount of labour and capital in an increasing returns to scale technology:

$$Y_{ij} = X_{ij}^{\lambda} \text{ with } \lambda > 1$$

with Y_{ij} denoting the output of the j'th intermediary firm in sector i, and $X_{ij} = \min(L_{ij}, K_{ij})$, which implicitly assumes that production requires one unit of labour to one unit of capital. The final good Y_i consists of a combination of one of the k intermediary goods, i.e., $Y_i = \min(Y_{i1}, .., Y_{ik})$.[2] Also for simplicity, the costs of assembling are put at zero, with perfect competition at the assembly stage. This makes it possible to interpret the complementarity as one arising in the consumption of goods, i.e., each intermediary producer sells directly to consumers and consumers need to combine intermediaries to obtain a final good.

[2] Allowing capital and labour to be substitutable in the production of intermediaries, or for an assembler to vary the inputs of different intermediaries was tried, but only added complications to the analysis of the competitive behaviour without changing the results qualitatively. An advantage of having fixed proportions of capital and labour is that for many analyses, the model can be interpreted as a single input model.

The important aspect of combining intermediaries is that the number of final goods produced rises more than proportionally with the number of intermediaries in that sector. The extreme assumption that all k intermediaries are indispensable for a final good is taken for simplicity.

In the island example, each sector is an island and there are four intermediary goods needed for a final good (air ticket, taxi, hotel, and leisure facility).

We will assume that the competitive process has yielded a single monopolist of each intermediary good, although we will consider deviations of this when discussing invention periods. The monopolies can arise from the increasing returns to scale, patent-entry-barriers, or "qwerty-barriers", where a qwerty-barrier denotes the situation that all users of the final and intermediary goods have invested in a consumption technology that only functions with a particular type of intermediary (see Davids (1985)). Keeping such a consumption technology avoids the search costs of finding a new consumption technology and may also enjoy network externalities. This protects each of the nk monopolists from a competitor wishing to contest the monopoly. Translated to the island example, the current hotel on island x is mentioned in the brochures of the air company and the leisure company on island x. Also, the hotel can provide as many places as could possibly be demanded at decreasing marginal costs. For a potential competiting hotelier this means that he not only has to commit by building a new hotel, but that even when the new hotel is built, the old hotel can always produce the same good for less money as it has regular customers who do not wish to incur the search costs of looking for new accommodation and because the new hotel has to advertise continuously in order to compensate for the fact that it is not yet mentioned in the brochures. Therefore, independently of the price the old hotel sets, a new hotel knows it will be driven out of the market once it enters and hence will not enter.

This setup is explicitly based on the empirical finding that industrial sectors often experience increasing returns to scale whereas agricultural and informal sectors do not: see Barro and Sala-i-Martin (1995) for a discussion of this topic.

The utility function of the representative consumer equals:

$$U = Y_0^{1-\delta}[\sum_{i=1}^{n} Y_i^{\gamma}]^{\frac{\delta}{\gamma}} \text{ with } \gamma < \frac{1}{\lambda} < 1$$

Hence with respect to the choice between the agricultural good and the intermediate goods, there are Cobb-Douglas preferences, whereas there are CES-preferences for the n goods. The constraint on γ ensures that it is not possible for one industrial sector to drive all other industrial sectors out of the market. In the island example, individuals want food (sector zero) and holidays (sectors i>0) and the holidays offered are sufficiently diverse to prevent one island from being able to attract all customers. There is no disutility of work. The budget constraint equals:

$$m = Y_0 + \sum Y_i P_i$$

with m the budget and P_i the price of good i. The price of the zero good is taken to be the numeraire.

The conditions for labour market clearing and capital market clearing are:

$$
\begin{aligned}
w &= \alpha(L - nkY_i^{\frac{1}{\lambda}})^{\alpha-1}(K - nkY_i^{\frac{1}{\lambda}})^{\beta} \\
r &= \beta(L - nkY_i^{\frac{1}{\lambda}})^{\alpha}(K - nkY_i^{\frac{1}{\lambda}})^{\beta-1}
\end{aligned}
$$

which takes account of the fact that in equilibrium each sector and each intermediary produces the same amount and hence that total labour and capital in the n sectors equals $nkY_i^{\frac{1}{\lambda}}$. Throughout it is assumed that the agricultural sector is big enough so that no individual intermediary producer or sector takes account of its influence on the price of capital or labour, which facilitates the analysis greatly. Similarly, no individual intermediary producer or sector will take its effect on the budget constraint into account.

From the utility function, we can calculate the demand for each individual sector depending on its price:

$$
\begin{aligned}
Y_0 &= (1-\delta)m \\
Y_i &= \delta\frac{mP_i^{\frac{\gamma}{\gamma-1}-1}}{\sum P_i^{\frac{\gamma}{\gamma-1}}}
\end{aligned}
$$

with $P_i = \sum_{j=1}^{k} P_{ij}$. In equilibrium Y_i equals $\frac{m\delta}{nP_i}$.

3 Coordination

3.1 investment coordination

The first coordination problem, the *investment* problem, arises when setting up an industrial sector and follows directly from the way industrial sectors are modelled. Suppose no intermediate good producers yet exist in sector i and consider the problem of each potential investor in sector i who loses a fixed cost when setting up an intermediary firm: if the potential investor in an intermediary firm believes that no-one else invest in other intermediaries, he will only invest in the sector if he is able to borrow enough money to set up the entire sector. Such *sector-monopolists* face severe borrowing constraints and pay high overhead costs which make them unlikely to occur: as Miyagawa (1993) and Stiglitz (1994) have argued, overhead costs, borrowing constraints, and the underlying information problems are the implicit defence for the standard assumption that there is more than 1 firm in the economy as a whole. Simply because of increased market power, a single firm could always outperform others in the absence of information problems and overhead costs. The assumption therefore that the same problems also prevent firms which produce complementary goods from merging or starting as a single firm, is standard. Then, an investor will only set up a new firm if he thinks that it is sufficiently likely that all the other intermediary firms will be set-up as well[3]. Three solutions to this coordination

[3] We may note that individuals in the informal sector have an incentive to let others believe that they are going to set up firms producing intermediary goods: if they would set up such goods, it becomes more likely for other potential investors that their investments will prove profitable. This would increase investments, raising the price of capital and labour in the

problem seem plausible. Firstly a government can step in, either by setting up a sector-monopolist who invests in the production of all intermediaries, or by simultaneously channeling investments into many different private companies. This seems one of the aspects of investment policies in Japan and South Korea for the last 50 years, where the governments either set up very large groups of companies or channeled investment simultaneously to many firms via the keiretsu and chaebol systems in Japan and South Korea respectively. If the government knows a certain intermediate technology exists, which will be the case if the sector as a whole exists in other countries, there will not be a principle-agent problem. If the sector is entirely new on the world-market however, misinvestment may occur on a large scale because the government has little information about the feasibility of the production techniques it subsidizes and hence faces large principle-agent problems. This may provide a partial explanation for the recent slow-down in economic growth in Japan and South Korea: for Japan at least, Callon (1995) argued that the industrial policies of the MITI and other government departments have proved ineffective after the 1970s in the sense that large investments in new technologies have not paid off.

A different way of solving the investment coordination problem may be a developed banking sector, where banks, either in cooperation with other banks or alone, coordinate investment in sectors. There are indeed banks, even in

informal sector, even if the individuals in the informal sector do not actually invest in a new intermediary. Announcing that one will invest in an intermediary will also discourage others from investing in that intermediary. This will allow the firm who announced his investment plans not to actually go through with his investments until he has observed others making investments in other intermediaries. Hence there is also a hold-up problem here. Both possibilities combine to make talk cheap and therefore incredible. There is good reason therefore to expect the market to be unable to solve the coordination problem.

highly industrialized societies, which specialize in particular sectors and hence gather private information as to the viability of certain projects. Because the bank exists in a competitive environment, its incentive to find such information will be higher than that for a central government. Banks may then be interpreted as centres where information about whole sectors is gathered, which saves all individual companies in a sector from making the search costs for this information and allows for more efficient coordination. This situation seems a possible description of investment practices in Germany (see for instance Edwards and Fisher (1994) for a discussion of the active role of banks in investment in Germany).

Thirdly, the investment coordination problem may be solved by a culture of optimism, a situation where investors expect there to be some other investor who will invest in other intermediaries. In equilibrium there then always will be some other investor who has invested in a different intermediary, hence validating the optimistic expectations. Perhaps this investment coordination mechanism is prevalent in the US, where the role of banks and government in investments seems relatively limited. Non-institutionalized investment coordination may for instance have lead to implementation cycles and investment bunching (Shleifer (1986), Cooper and Haltiwanger (1996)).

3.2 price coordination

Consider first the case where there are n+1 sectors and no intermediary producer coordinates. The profit function of an individual intermediary firm reads:

$$\pi_{ij} = P_{ij}Y_i - Y_i^{\frac{1}{\delta}}(w+r)$$

The first order condition for profit maximization of an intermediary then equals

$$\begin{aligned}\frac{d\pi_{ij}}{dP_{ij}} &= Y_i + P_{ij}\{\frac{m\delta}{nP_i^2}\frac{-1}{1-\gamma} + \frac{m\delta}{P_i^2 n^2}\frac{\gamma}{1-\gamma}\} \\ &\quad -\{\frac{m\delta}{nP_i^2}\frac{-1}{1-\gamma} + \frac{m\delta}{P_i^2 n^2}\frac{\gamma}{1-\gamma}\}Y^{\frac{1}{\lambda}-1}\frac{1}{\delta}(w+r)\end{aligned}$$

we may note that the individual intermediary firms takes no account of the demand effect on the other intermediary firms in his sector of an increase in his own price. In equilibrium all the intermediary prices have to be the same and therefore $P_i = kP_{ij}$ and $Y_i = \frac{\delta m}{nP_i}$. This means we can rearrange the first order condition to find

$$0 = k + \frac{-1+\gamma/n}{(1-\gamma)} + k\frac{1-\gamma/n}{1-\gamma}\frac{(m\delta)^{\frac{1}{\lambda}-1}}{n^{\frac{-1}{\lambda}+1}}P_i^{-\frac{1}{\lambda}}\frac{1}{\lambda}(w+r) > 0$$

which only has a solution for $\gamma > \frac{k-1}{k-\frac{1}{n}}$ which corresponds to a very high degree of substitutability of final goods. Hence for most reasonable values of γ, $\frac{d\pi_{ij}}{dP_{ij}} > 0$ and there is no finite equilibrium price and the individual intermediary firm will put up its prices to infinity and produce virtually nothing. The profit made in each firm then equals $\frac{\delta m}{nk}$. The economic intuition is that the actions of one intermediary cannot increase the demand for other intermediaries, but can

only decrease the demand for the other intermediaries. Each firm increases its prices as a reaction to the price increases of all others in the economy. There is a price-race to infinity if firms do not coordinate. Only if the substitutability of final goods is very high, will there be a finite equilibrium price.

If all intermediaries within a sector coordinate, their sector can obtain a much higher share of the budget if other intermediaries in other sectors do not coordinate. Then all intermediary firms will try to coordinate within their own sectors. The first order condition for a sector whose intermediaries coordinate when other sectors also coordinate reads

$$\frac{d\pi_i}{dP_i} = Y_i + P_i\{\frac{m\delta}{nP_i^2}\frac{-1}{1-\gamma} + \frac{P_i^{-2}m\delta}{n^2}\frac{\gamma}{1-\gamma}\} - k\{\frac{m\delta}{nP_i^2}\frac{-1}{1-\gamma} + \frac{P_i^{-2}m\delta}{n^2}\frac{\gamma}{1-\gamma}\}Y^{\frac{1}{\lambda}-1}\frac{1}{\lambda}(w+r)$$

which reduces in equilibrium to

$$P_i = \left[\frac{\gamma(n-1)}{k(n-\gamma)(w+r)}\frac{(m\delta)^{1-\frac{1}{\lambda}}}{n^{\frac{1}{\lambda}-1}}\lambda\right]^{-\lambda}$$

which decreases in γ, m, λ and n and increases in k. The increase in k is because production becomes relatively more expensive when there are more intermediaries due to the lesser degree to which the increasing returns to scale are enjoyed. The other results are like that of monopolistic competition. Hence, we get the counter-intuitive result that coordination between monopolists in each sector improves the outcomes of the economy in the sense that prices of goods are lower, output is higher and aggregate welfare is higher. This is

also a self-sustaining equilibrium because when the coordination breaks down in any particular sector, the resulting price increases in that sector will reduce the profits of all the intermediary firms in that sector and will increase profits elsewhere. This result critically rests on the assumption that each intermediary good is produced by a monopolist however, as unrestricted competition for all intermediary goods would not lead to high prices.

If all nk intermediaries coordinate with all other intermediaries, it is no longer reasonable to assume that m and w are taken constant. If we solve the maximization problem of the n sectors combined, inserting the now endogenous m ,w, r, P_i,and Y_0, we find the problem becomes

$$\begin{aligned}\pi &= \frac{\delta}{1-\delta}[(L-nkY_i^{\frac{1}{\lambda}})^{\alpha}(K-nkY_i^{\frac{1}{\lambda}})^{\beta}] \\ &\quad -nkY_i^{\frac{1}{\lambda}}(\alpha(L-nkY_i^{\frac{1}{\lambda}})^{\alpha-1}(K-nkY_i^{\frac{1}{\lambda}})^{\beta}+\beta(L-nkY_i^{\frac{1}{\lambda}})^{\alpha}(K-nkY_i^{\frac{1}{\lambda}})^{\beta-1})\end{aligned}$$

when taking the derivative to Y_i and rearranging we get

$$\begin{aligned}\frac{\partial\pi}{\partial Y_i} &= nk\frac{1}{\lambda}Y_i^{\frac{1}{\lambda}-1}(L-nkY_i^{\frac{1}{\lambda}})^{\alpha}(K-nkY_i^{\frac{1}{\lambda}})^{\beta}* \\ &\quad \{\frac{-1}{1-\delta}[\alpha(L-nkY_i^{\frac{1}{\lambda}})^{-1}+\beta(K-nkY_i^{\frac{1}{\lambda}})^{-1}] \\ &\quad -nkY_i^{\frac{1}{\lambda}}[\alpha(1-\alpha)(L-nkY_i^{\frac{1}{\lambda}})^{-2} \\ &\quad +2\alpha\beta(L-nkY_i^{\frac{1}{\lambda}})^{-1}(K-nkY_i^{\frac{1}{\lambda}})^{-1} \\ &\quad -\beta(1-\beta)(K-nkY_i^{\frac{1}{\lambda}})^{-2}]\}\end{aligned}$$

The second line is always negative. The combined third to fifth line are also always negative. To see this, note that they are positive if and only if

$$\alpha(1-\alpha)Z^{-1} + \beta(1-\beta)Z < 2\alpha\beta$$

with Z=$(L - nkY_i^{\frac{1}{\lambda}})^1(K - nkY_i^{\frac{1}{\lambda}})^{-1}$. We can easily see that because (1-α)>β and (1-β)>α this inequality will never be satisfied for any value of Z, α, and β. Therefore $\frac{\partial \pi}{\partial Y_i} < 0$ and output in the industrial sectors will become minimal and prices will be infinite.

Although this case seems very unrealistic, it may be a mechanism through which a top-layer of industrialists in a country is able to extract surplus from the rest of the population: by monopolizing the modern sectors, preferably keeping the number of modern sectors low in order to avoid coordination problems and reduce spreading of the surplus, an elite would be able to extract high rents for low effort. Of course such an economy-wide monopoly would have to be sustained by high entry barriers and by barriers to imports (except perhaps imports for the consumption of the elite).

4 The process of inventing a new sector

New sectors are set up at the beginning of the period in consideration and the invention process is assumed to take place in negligible time. Consider the case when there are initially n-1 industrial sectors and the possibility of starting a new industrial sector arises and it is believed that this will be the only possible

new sector. The new sector is discovered in a hierarchical manner, i.e., the j'th intermediary in sector i can only be sought when the (j-1) intermediaries of sector i are already found. It is not actually necessary that intermediates are indeed hierarchically ordered, only that discoveries are made sequentially: investors can join in the search for intermediary x as long as x is not yet found. In the development of computers for instance, the invention process took decades and had several sequential steps involved (Williams (1985)).

Investors in the j'th intermediary know how many other investors there are in the j'th intermediary, know whether investment will take place for subsequent intermediaries and know that there is a probability p for each intermediary that it does not exist. The intermediary will always be found if it exists, as long as there is at least one investor who searches it. Searching a new technology carries a fixed labour and a fixed capital cost, equal to C=$c_L w + c_K r$. In line with the arguments of Dixit and Pindyck (1994) and Arrow (1968), this is considered a sunk cost. For simplicity, the effect of the new sector on capital and wages is sufficiently small to neglect and there is price-coordination within sectors, but not between sectors. This implies that the possible profits of each intermediary firm in the new sector equals $\pi = \frac{m\delta}{nk} - \frac{\gamma(n-1)}{k(n-\gamma)} mn\delta\lambda$, which is declining in k and n, as expected.

The problem of the investment behavior of successive investors is solved by means of backward induction. If the k-1 other intermediaries are already found, the value of finding the last intermediary equals $\pi(1-p)$. Hence there are then $\frac{\pi(1-p)}{C}$ investors at that stage. The number of investors of the j'th

intermediary equals $\frac{\pi(1-p)^{k-j+1}}{C}$, which increases with j. This complies with the impression that in research markets the number of entrants and the research activities is greatest when the final applications are nearest. With probability $(1-p)^{j-1}p$, the process of finding all the intermediaries breaks down for intermediary j, which entails a total cost of $\sum_{l=1}^{j}\pi(1-p)^{k-l+1}$. A new technology therefore takes $\pi\frac{1-(1-p)^{k+1}-p}{p}$ in research costs if all intermediaries are discovered, which happens with a probability of $(1-p)^k$, whilst there is an expected cost $\pi\{p\sum_{i=0}^{k-1}\sum_{j=0}^{i}(1-p)^{k-j+i}\}$ which occurs when not all intermediaries are found.

On average there are hence $\frac{\pi\{p\sum_{i=0}^{k-1}\sum_{j=0}^{i}(1-p)^{k-j+i}\}+(1-p)^k\pi\frac{1-(1-p)^{k+1}-p}{p}}{(1-p)^k} = \pi k$ spent research costs per discovered new sector, which is the direct result of the free entry assumption at the invention stage. This level of investment is not efficient for two reasons. Firstly, there is over-investment for each intermediary good due to the sunk costs and due to the assumption that p does not depend on the number of investors. Secondly, the value of the new sector to the investors is greater than the value to the economy as a whole, which is due to the negative effect of the declining output in all other sectors that occurs when a new sector is discovered. These inefficiencies are a direct result from the market distortion after invention, i.e., the monopolies. To a certain extent such efficiency losses of innovation are unavoidable in market economies, because the incentive for innovation comes from the market imperfection: with no market imperfection after invention, no profits can be made of inventions and hence no inventions: see also Walde (1998), Cheng and Dinopoulos (1996)),

and Barro and Sala-I-Martin (1995) for extensive analyses of invention cycles and their inherent inefficiencies. The invention process doubles the inefficiency of monopolies because an inefficient amount of resources is spent to become the monopolist in order to obtain the inefficient rents associated with monopolies.

Another possible dynamic feature arising from the invention process may be seen by interpreting the new sector as producing the same final good as an already existing "old" sector more cheaply. If for instance the productivity in the new sector is only very slightly above that in the old sector, and the final goods are otherwise identical, the new sector will still completely replace the old sector when it arrives because it can always undercut the old technology (see Walde (1998) for a similar argument connected with new production techniques). Macro-economic fluctuations may then not only arise due to the labour and capital destruction during R&D, but also may arise if the labour and capital replacement from the old sector to the new takes some time and causes frictional unemployment, as in Aghion and Howitt (1994).

5 Welfare analysis

Here we address the question how the complementarities, monopolies, and ensuing search inefficiencies affect the number of sectors. We consider four cases. First we look at the optimal number of sectors as a social planner would set them, assuming that each sector is known to exist and hence only the costs C need to be paid for each intermediary. For simplicity and tractability we reduce

the model here to a one-factor input, i.e. K=L and $c_k = c_l = c$. Aggregate welfare then becomes:

$$U = (L - nkY_i^{\frac{1}{\lambda}} - nck)^{(\alpha+\beta)(1-\delta)} n^{\frac{\delta}{\gamma}} Y_i^{\delta}$$

maximization with respect to Y_i and n leads to:

$$\begin{aligned} n &= \frac{\delta L}{\frac{ck}{-\lambda+\frac{1}{\gamma}}(\alpha+\beta)(1-\delta) + \frac{\delta\lambda ck}{-\lambda+\frac{1}{\gamma}} + \delta ck} \\ Y_i &= \left[\frac{\lambda c}{-\lambda + \frac{1}{\gamma}}\right]^{\lambda} \end{aligned}$$

If new technologies are uncertain, then for expected utility the only thing that changes is the expected costs of an intermediary in a new sector, c*, which then equals $\frac{c\sum_{i=1}^{k} p^i(1-p)^{k-i}(k-i+1)+k(1-p)^k}{k(1-p)^k}$. In both cases therefore the socially optimal number of sectors rises with L, γ and δ, and decreases with $(\alpha+\beta)$, c, k, and λ. These relationships all seem intuitively plausible.

Comparing these outcomes with the outcome in the absence of a social planner, it is assumed that there is coordination within but not between sectors. Equating the cost of investing in the first intermediary with the marginal benefit yields

$$\frac{c}{(1-p)^k}(w+r) = \pi = \frac{m\delta}{nk} - \frac{\gamma(n-1)}{k(n-\gamma)} mn\delta\lambda$$

which, unfortunately, yields an intractable four-degree polynomial for n as a

solution when m and (w+r) are inserted.[4]

Although there is no tractable solution for n in general in the case of uncertainty, we can consider qualitatively the question whether the absence of social planning would result in more or less sectors. First, if new sector are certain, i.e. p=0, then new sectors will be introduced until the profit of a new intermediary equals costs. In that case, the amount of labour and capital lost in the discovery of each new sector is the same as in the social planners case because investors take into account how many new sectors in total will be found at the beginning of the new period and hence will all invest at the point where the marginal benefits precisely outweigh the costs and when thus only one investor invests in each intermediary. In that case there is no inefficiency in the invention process and therefore the number of sectors found will be higher than in the social planners case, because investors will not concern themselves with the negative effect of new sectors on the profits of other sectors. In the case of no uncertainty therefore, the number of new sectors will be greater than in the social planners case. If p>0 there are two opposing forces. Without planning, setting up sectors costs more capital and labour due to the inefficiency in the invention process[5], which will increase the costs of labour and capital which decreases the number

[4] In order to get some analytical feeling for the solution, take the case when $(\alpha+\beta)$=1, and $\frac{n-1}{n-\gamma} \approx 1$. Then m=L(w+r) and n=$\frac{-\frac{ck}{(1-p)^k}+\sqrt[2]{(\frac{ck}{(1-p)^k})^2+4L^2\delta^2\lambda\gamma}}{2L\delta\lambda\gamma}$, which is lower than the social planner n for very large p and k due to the large inefficiencies. It is higher for values of $\gamma\lambda$ close to 1 (because then the social planner n goes to zero). For relatively high values of $\frac{ck}{(1-p)^k}$, the market n converges to $\frac{L\delta(1-p)^k}{ck}$, which is lower than the social planner n under all conditions.

[5] The efficiency loss of the invention process in the market will equal $c(k-\{\sum_{i=1}^{k} p^i(1-p)^{k-i}(k-i+1)+k(1-p)^k\})$ per new sector, which is zero with p=0 or k=1 and then rises with p and k.

of new sectors. On the other hand, each individual investor does not take the effect of the new sector on the profitability of the old sectors into account. If k and/or p are small therefore, the first effect will be small as the efficiency loss is then small. If λ and/or γ are low, the decrease in the profitability of the other sectors due to extra new sectors will be low and hence the second effect will be low.

5.1 International trade and endogenous growth

If the model above is correct, international trade between identical countries leads to complete specialization. In order to see this, imagine there are two economies with the structure above which are identical in capital and labour endowments and each have n identical sectors. Assume iceberg transport costs equal to fraction t, intermediaries can price discriminate between countries, there is no government intervention in trade and there is within-sector price-coordination. Then, if t>1-$\frac{1}{2^{\lambda}-1}$, no intermediary producer ij could increase profits by doubling his production and underprice the foreign producer of ij[6] and hence no trade at all will take place. If t<1-$\frac{1}{2^{\lambda}-1}$, intermediaries can make positive profits by exporting and complete specialization will occur because the increasing returns to scale ensures that there then can be only one producer of each intermediary. Each of the two countries will end up on average with n/2

[6] The implicit assumption here is that a monopolist will start exporting if he can produce the exported goods at lower costs than his foreign competitor, because then he can drive his competitor out of the market. Because there is only price coordination, the amount one can sell in another country is fixed by the prevailing output of the other intermediaries in that sector in that country. For the threshold level this means that the amount of exports must be exactly as high as home sales. If whole sectors can coordinate on exports as well, the threshold level will probably be lower.

sectors. The reason is that if one country had more than n/2 sectors, wages and capital costs would be higher and each intermediary product could be made more cheaply in the other country. It is profitable for all the intermediary producers in sector i to be in one country as that will be the country were consumption of that final good is greater due to the lower prices in that country which are the result of the zero transportation costs within a country. This makes total costs lower for sectors which are completely based in one country, rather than divided over two countries. This means that if one particular country has more intermediaries of a sector than the other, all intermediary firms in that sector could increase profits by moving to that particular country.

Because of the limited substitutability between labour and capital in the model, long term growth can only occur when the labour force grows, such as for instance occurs if countries increasingly specialize and hence increases the population base of the combined economies. Within the model, economic growth is therefore attributed to increasing regionalization, meaning less sectors in each region, state or country separately. Because there are no complementarities between sectors, such as when each final good is an intermediary in the production of other final goods (see e.g. Cooper and John (1988) and Krugman and Venables (1995) for such specifications), specialization could benefit all countries and regions because it takes advantage of the increasing returns to scale in each sector. Specialization is very unlikely to be the only source of economic growth however, and the model's usefulness for analyzing endogenous growth issues is therefore limited. For analyses of other possible endogenous

growth dynamics associated with complementarities, see Redding (1996) and Durlauf (1993).

The only candidate to explain underdevelopment and the lack of foreign investment in some LDCs in this model is the coordination problem of investment: if one intermediary producer invests in a firm in an LDC, but other intermediary producers do not, the single firm has to import all the other intermediaries from abroad in order to make a final good, incurring high transportation costs. If all intermediary firms invest in the same LDC, the cost of the final good does not have to include the transportation costs and would be more profitable. Hence, the model would lead us to expect to see bunching of investment: either all intermediaries of a sector are set up at the same time in the same country or region or none is. Indeed, such investment bunching has been observed in the US by Cooper and Haltiwanger (1996). The increasing returns to scale make it more profitable to invest simultaneously in a populous region than in a non-populous region. As South East Asia is more densely populated than Africa or Latin America, this could be a factor in their recent growth records.

Another aspect of the model which may be important for international trade is the timing of investments: if there are international patent considerations or qwerty barriers or low transportation costs, the speed of investment may provide a competitive advantage for a country as a whole. In that case, optimism seems the fastest way of coordinating, given that government and banking intervention may take time because investments can only be subsidised or coordinated some time after they are identified as in need of subsidies or coordination.

6 Conclusions and discussion

Put in terms of the example of the fictitious islandgroup of Tawahu, the key assumption in this paper is that a holiday on any island needs all the facilities present (air ticket, taxi, hotel, leisure activity) where each facility is operated by a different monopolist.

The assumed complementarities (taxis and hotels on one island are both needed for a holiday) and natural monopolies (increasing returns to scale lead to only one hotel and leisure facility) in the non-agricultural sectors (islands) had two important implications. The first implication is that it is necessary to coordinate investment, either by means of intervention from government or banks, or by means of mutually optimistic expectations on the side of many investors in a sector. Obviously, coordination will be even harder to achieve when it concerns investments abroad that have to coincide with investments of many other foreign firms, which is a possible explanation for the lack of (foreign) investments in some LDCs. Within a country however, when investors can coordinate without intervention, the monopolies which investors obtain after setting up a firm induce inefficiencies because too much investment will take place within a sector.

The second implication is that price coordination within sectors is beneficial for welfare as it decreases prices and increases output compared to the no-price-coordination case. Price-coordination between sectors leads to very high prices and very low output and corresponds to the situation whereby a small industrial elite obtains part of the surplus produced by the agricultural sector

by means of monopolizing the industrial sectors. In the complete absence of any price-coordination and as long as the substitutability of final goods is not near-perfect, each intermediary will produce virtually nothing and will put up its prices to infinity. Therefore the situation with complete coordination between all industrial firms is the same as without any coordination.

The assumptions on complementarities in this paper are extreme. The advantage is that this makes clear what the maximum effect is of complementarities. The disadvantage is that there is a loss of realism. The results in this paper should therefore be taken only as an indication of the possible consequences of complementarities and natural monopolies.

Literature

1. Aghion, P., and P. Howitt (1994), "Growth and unemployment", *Review of Economic Studies*, 61(3), pp. 477-494.

2. Arrow, K.J. (1968), "Optimal capital policy with irreversible investment", in Wotlfe, J.N. (ed.), *Value, capital and growth: papers in honour for sir John Hick*, Edinburgh University Press, Edingburgh.

3. Barro, R.J., and X. Sala-i-Martin (1995), *Economic growth*, McGraw-Hill: New York.

4. Bartelsman, E., Cabballero, R., and R. Lyons (1994), "Customer- and supplier-driven externalities", *American Economic Review*, 84(4), pp. 1075-84.

5. Callon, S. (1995), *Divided sun: MITI and the breakdown of Japanese high-tech industrial policy, 1975-1993,* Stanford University Press, Stanford.

6. Cheng, L.K., and E. Dinopoulos (1996), "A multisectoral general equilibrium model of Schumpeterian growth and fluctuations", *Journal of Economic Dynamics and Control*, 20, pp. 905-923

7. Cooper, R.W., and J. Haltiwanger (1996), "Evidence on macro-economic complementarities", *Review of Economics and Statistics*, 78(1), pp. 78-93.

8. Cooper, R.W., and A. John (1988), "Coordinating coordination failures in Keynesian models", *Quarterly Journal of Economics*, 103, pp. 441-463.

9. Cooper, R.W., and A. Johri (1997), "Dynamic complementarities: a quantitative analysis", *Journal of Monetary Economics*, 40(1), pp. 97-119.

10. David, P.A. (1985), "Clio and the economics of qwerty", *American Economic Review*, 75(2), pp. 332-337

11. Durlauf, S.M. (1993), "Nonergodic economic growth", *Review of Economic Studies*, 60(2), pp. 349-366.

12. Edwards, J., Fischer, K. (1994), *Banks, finance and investment in Germany,* Cambridge University Press.

13. Krugman, P.R., and A.J. Venables (1995), "Globalization and the inequality of nations", *Quarterly Journal of Economics*, 110(4), pp. 857-880.

14. Lin, H.C. (1995), "Targeted tariff protection, monopolistic competition

and demand interdependence", *International Economic Journal*, 10(2), pp. 25-49.

15. Milgrom, P. and J. Roberts (1995), 'Complementarities and fit: strategy, structure and organisational change in manufacturing", *Journal of Accounting and Economics*, 19, pp. 179-208.

16. Miyagawa, T. (1993), "Complementarities and cumulative processes in models of monopolistic competition", *Journal of Economic Literature*, 33(2), pp. 701-729.

17. Miyagawa, T. (1996), "Industry complementarities and investment behaviour", *Economic Review*, 47(4), pp. 301-312.

18. Redding, S. (1996), "The low-skill, low-quality trap: strategic complementarities between human capital and R&D", *Economic Journal*, 106, pp. 458-470.

19. Shleifer, A. (1986), "Implementation cycles", *Journal of Political Economy*, 94(6), pp. 1163-1190.

20. Stiglitz, J.R. (1994), *Whither socialism*?, Cambridge University Press; Mass.

21. Walde, K. (1998), "On the endogeneity of Kondratieff cycles", Economic *Discussion Paper 97-16*, University of Dortmund.

22. Williams, M.R. (1985), *A history of computing technology*, Prentice Hall, Londen