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NATIONAL SYSTEMS OF INNOVATION UNDER STRAIN: THE INTERNATIONALISATION OF CORPORATE R & D

by

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SUMMARY

The central components of national systems of innovation in the advanced OECD countries are the innovative activities performed by practitioners (mainly businesses), and the basic research and related training performed by universities. The close linkages observed between the national science base and innovative activities in nationally owned firms reflect the advantages of physical agglomeration in innovative activities, and allow companies and countries to extract major economic benefits from their investments.

However, national systems of innovation are under increasing strain, because of emerging imbalances between what the science base has to offer, and the demands of the technology system. These imbalances reflect the combined effects of (1) the liberalisation of international exchanges, (2) uneven rates of national technological development, (3) increasing pressures of competition, (4) the increasing range of fields of potentially useful technology.

These imbalances have long been felt by large firms in smaller countries. They have recently been experienced in different forms in Germany, Japan and the UK, in the last of which the dominant links between the science base and national firms has virtually disappeared in the electronics industry, and been replaced by more complicated links with foreign firms. These are likely to grow in all countries in future.

1. NATIONAL SYSTEMS OF INNOVATION

We shall explore below the growing strain between national systems of innovation, on the one hand, and the internationalisation of corporate innovative activities, on the other. What national systems of innovation encompass and what they actually do is still subject to varying interpretations and debate (Freeman, 1995; Lundvall, 1992; Nelson, 1993; Patel and Pavitt, 1994; Edquist, 1997). In broad terms, they can be defined in terms of the institutions involved in the generation, commercialisation and diffusion of new and better products, processes and services (i.e. technical change), and of the incentive structures and competencies in these institutions that influence the rate and direction of such change. In the context of this volume's primary concern with technical change, productivity and competitiveness, we can get by with a more restricted definition, namely, the national investments in the knowledge-generating activities that are a necessary complement to investments in equipment in increasing efficiency and in maintaining or increasing competitiveness. Recent research on why national growth rates differ identifies two essential components of such knowledge-generating activities: education and training in all countries, and R & D in the industrially advanced countries (Fagerberg, 1994). In this paper, we shall concentrate on the latter[1].

One essential element of contemporary knowledge generation[2] is its specialised nature.

- Specialisation by discipline within science and technology.
- Specialisation by corporate function inside the business firm, with the establishment of R & D laboratories. And - within the corporate R & D function - specialisation between the development function concerned with product and process development, and the research function exploring options for future product development.

[1] On the former, see Prais (1993)
[2] The currently fashionable term is "knowledge production".

- Specialisation by institution within countries, with R & D laboratories funded by companies, and by governments - either directly or through universities and similar organisations.

Specialisation implies co-ordination - and even integration - so that an essential feature of all effective "systems of innovation" are the linkages (networks) between their component parts: between disciplines, between corporate functions and between institutions. Our concern here are institutional linkages - between corporate R & D, on the one hand, and the publicly funded "science base" in universities and similar institutions, on the other. In this context, recent empirical research confirms the existence of *national* systems of innovation. There is a strong national bias in linkages between business practitioners and academic research (Hicks et al, 1996; Narin et al., 1997). This reflects the linguistic and geographic constraints imposed by person-embodied exchanges and transfers of tacit knowledge[3]. As a consequence, high quality basic research in an OECD country (measured as citations per published paper) is correlated with high level technology (measured as business-funded R & D as a share of GDP) (Patel and Pavitt, 1994; Kealey, 1996). In addition, Arundel and his colleagues (1995) have shown that non-market corporate linkages to "public knowledge" are in fact much more difficult to forge across national boundaries than within them.

It is in this context that we shall now examine the implications of the "globalisation" of corporate activities for the so far privileged links between the national science base and national innovative activities. Scholarly opinion on what is in fact happening is divided[4]. We shall first present the facts of the case, before identifying underlying causal factors and implications for national and corporate policies.

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[3] For the importance of distance, see Jaffe (1989). For the usefulness of academic research, see Martin and Salter (1996)

[4] Compare, for example, Dunning (1992) who argues that the links between globalised firms and their technological home base are becoming weaker, Porter (1990) who argues that they continue to be strong, and Vernon (1979) who takes a position in between.

2. THE INTERNATIONALISATION OF CORPORATE R & D

Most studies concerned with analysing the internationalisation of corporate R & D are based on one of two sets of measures:

- *R&D expenditures and employees*, where the OECD (1997) has recently brought together evidence from national surveys on the shares of domestic business funded R & D performed by foreign firms, and of R & D funded by domestically owned firms that is performed outside their home country
- Patent statistics (Etemad and Seguin-Delude, 1987; Cantwell, 1992; Patel and Pavitt, 1991; Patel, 1995,1996; Patel and Vega, 1997, 1998) where the inventor's address given in each published patent is used as a proxy measure for the geographical location of R & D activities

This section is based mainly on the results of our own research based on firm level patent data. The validity of this measure has been extensively discussed elsewhere[5]. Suffice to say that patenting-based data can be analysed in much greater detail and with much greater consistency than the available data on R & D activities. Moreover, as we shall now see, the patterns revealed by these patenting statistics are consistent with those revealed by the R & D statistics that are available[6].

2.1 Continuing Reliance on the Home Country

Our most recent research (Patel and Vega, 1998) is based on a systematic analysis of 359 of the world's largest companies[7] (from the Fortune 500 list) that were technologically active in the 1990s. Table 1 shows that the patenting and the R & D data tell the same story[8]. Firms continue to perform a high proportion of their

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[5] See, for example, Cantwell (1992) and Patel (1995 and 1996).

[6] See also Patel (1995 and 1996).

[7] In terms of nationality, 136 are European, 128 American and 95 Japanese.

[8] The larger share of foreign patenting than foreign R & D for the European and Japanese based firms probably reflects differing populations, since our patenting data covers only large firms which typically have a higher share of foreign activities. The lower share of foreign patenting for the US based firms probably reflects the higher propensity of US based firms to patent in the USA from their domestic base than from foreign countries.

TABLE 1. INTERNATIONALISATION OF CORPORATE TECHNOLOGY.

Nationality	% share of US Patents in 1992-96		% share of R&D Exp. Abroad	Change in % Abroad (US Patents) Since 1980-84
	Home	*Abroad*		
Japan	97.4	2.6	2.1 (1993)	-0.7
US	92.0	8.0	11.9 (1994)	2.2
Europe	77.3	22.7*		3.3
Belgium	33.2	66.8		4.9
Finland	71.2	28.8	24.0 (1992)	6.0
France	65.4	34.6		12.9
Germany	78.2	21.8	18.0 (1995)	6.4
Italy	77.9	22.1		7.4
Netherlands	40.1	59.9		6.6
Sweden	64.0	36.0	21.8 (1995)	-5.7
Switzerland	42.0	58.0		8.2
UK	47.6	52.4		7.6
All Firms	87.4	12.6	11.0 (1997)	2.4

* The proportion of total activities for all the European countries listed in this table located outside Europe.
Source for R&D data: OECD (1997), EC (1997).

innovative activities in their home[9] countries. Japanese firms have the least "globalised" structure of innovative activities, and European firms the most. Within Europe, the share of corporate technological activities performed outside the home country is higher for firms from small countries (more than 50% in those from Belgium, Netherlands and Switzerland) than in those from large countries (a third or less in firms from France, Germany and Italy). But there are exceptions, with large firms from the UK performing more than half outside the UK and Finnish firms performing only about a quarter outside Finland.

From the early 1980s and the mid-1990s, large firms increased the proportion of their innovative activities performed outside their home country by a modest 2.4%. The

[9] Country of the headquarters of the parent group

increases for European firms were larger, but the Japanese firms show a decrease. Within Europe, increases were highest for French firms, who expanded their activities more in other European countries than the US (Patel and Vega, 1998). Our earlier analysis showed that most of the increases in foreign shares have been consequences of foreign acquisitions, rather than of an international redeployment of R & D activities (Patel, 1995).

Contrary to a widely held view, the degree of internationalisation of R & D is not positively associated with high technology. Table 2 shows that, with the notable exception of pharmaceuticals (and to a lesser extent chemicals), the proportion of firms' innovative activities performed domestically *increases* with the technology intensity of the industry. Our previous analysis (Patel, 1996)) showed that this relationship also holds at the level of the firm. This reflects the influence of the following factors:

- at the industry level, the need to adapt "traditional" products to local tastes (e.g. food and drink, building materials), and to locate technological activities close to available raw materials (e.g. petroleum, food and drink, building materials);

- at the industry level, the smaller need to adapt high-technology products (e.g. civil aircraft, automobiles) to local requirements;

- at the industry and the firm level, (a) the positive external economies of links with the local science base and supply of skills, sources of finance, and local suppliers and customers (Vernon, 1960, 1966); (b) the efficiency gains within firms from the close co-ordination of functional activities, and the integration of tacit knowledge, necessary for the launching of major innovations (Rothwell, 1977; Patel and Pavitt, 1991).

TABLE 2. A COMPARISON OF LARGE FIRMS' PATENTING AT HOME, AND THEIR R&D INTENSITY, BY PRODUCT GROUP.

Principal Product Group	% of Patenting in Home Country (1992-96)	R&D Intensity* (1992)
Food, Drink and Tobacco	56.3	1.0
Rubber & Plastics	71.4	2.5
Pharmaceuticals	78.3	10.4
Chemicals	78.5	4.5
Mining & Petroleum	80.4	0.7
Building Materials	83.2	1.8
Metals	87.7	1.3
Electrical/Electronics	87.7	6.1
Machinery	88.5	2.3
Computers	92.5	7.0
Motor Vehicles and Parts	93.6	4.0
Paper	93.7	1.0
Aerospace	94.1	6.9
Photography and Photocopy	95.0	5.9
All Firms	12.6	4.0

* R&D as a proportion of sales.

2.2 Location of Foreign Corporate R&D: 'Triadisation' not 'Globalisation'

Less than one percent of these firms' foreign innovative activities are located outside the 'Triad' countries, showing that the process of internationalisation of technological activities can at best be described as 'triadisation' rather than 'globalisation. Within the 'Triad' countries, Japan is the least favoured foreign location, and US, Germany and the UK the most favoured, together accounting for around 70% of all foreign technological activities. In our previous research (Patel 1995), based on a larger population of firms (around 600), we showed that about 60% of the firms had no foreign technological activity at the end of the 1980s, about a quarter were active in one or two foreign countries, and only about 15% in more than two.

2.3 Large Foreign Firms in Host Countries' Innovative Activities.

Table 3 shows that foreign large firms are relatively much more important sources of innovative activities in Europe than in either Japan or the USA[10]. The share of foreign large firms in national innovative activities in most European countries lies between 10 and 20%, with Finland and Switzerland as outliers with substantially less than 10%.

TABLE 3. IMPORTANCE OF FOREIGN LARGE FIRMS IN NATIONAL TECHNOLOGY: 1992-96.

% of National Totals	**Foreign Controlled US Patenting (1992-96)**	**Foreign Controlled R & D**	**Foreign Controlled Production (1994)**
Japan	1.1	1.3 (1991)	2.8
US	4.0	11.3 (1994)	15.5
Europe	12.4*		
Austria	12.5		25.7**
Belgium	53.6		
Finland	3.7	7.3 (1995)	7.6
France	11.3	13.0 (1992)	21.0
Germany	9.6	14.1 (1993)	28.1
Italy	10.0		
Netherlands	13.2	14.8 (1995)	42.4
Sweden	13.6	11.2 (1994)	18.7
Switzerland	5.8		
UK	20.3	15.0 (1994)	22.3

* *Foreign* here refers to the share of all non-European firms.
** 1991
Source: OECD (1997) and Patel and Vega (1998).

Table 3 also shows that in general foreign firms account for a larger proportion of industrial production than of technology (measured in terms of both patenting and R & D), thereby confirming that on average foreign firms have a lower technology intensity than domestic firms[11].

[10] The patenting data underestimate the foreign share of technological activities in the USA, because of the lower propensity of foreign firms to patent in the USA than US-based firms

[11] See also Cantwell (1995).

2.4 Domestic and Foreign Firms in National Systems of Innovation

Table 3 showed that, amongst the larger R&D spending countries, the UK has a higher proportion of national technological activities performed by foreign firms. Table 4 below compares the UK with other major countries in more detail in six broad technological fields covering all technological activities. It shows that the predominance of foreign firms is even more pronounced in electrical and electronics technologies, where foreign firms are more than twice as important as national firms in British technological activities. Since the late 1960s, the proportion of innovative activities in electronics accounted for by UK owned companies has declined rapidly, so that in the mid-90s around 50% or more of the total was performed by foreign firms in four out of the five of the electronics fields (computers, semiconductors, image & sound and photography & photocopying). In three out of these four fields, UK's largest electronics company, GEC, has seen its share decline to around half its value in 1969-73. No other major OECD country has a similar pattern.

Table 4 Relative Importance of National and Foreign Large Firms, By Broad Technical Field: 1992-96

% of National Totals	Japan		USA		France		Germany		UK	
	Nat.	**For.**	**Nat.**	**For.**	**Nat.**	**For.**	**Nat.**	**For.**	**Nat.**	**For.**
Electrical & Electronics	73.4	0.9	39.3	3.9	40.4	13.1	47.8	17.2	14.4	33.0
Chemicals & Pharma.	45.6	1.9	39.1	9.1	42.6	15.2	71.8	7.2	36.8	24.4
Process Technology	53.8	1.8	32.6	6.3	51.6	7.9	57.2	8.8	33.6	17.0
Automobiles	81.1	0.4	36.0	3.5	22.0	15.0	63.4	3.0	30.7	22.1
Machinery & Aircraft	40.4	0.8	14.5	1.8	27.5	8.3	22.4	8.1	14.3	11.6
Instruments & Controls	58.3	0.8	27.3	2.6	36.2	10.0	38.8	10.4	13.8	11.7
Consumer Goods	20.8	0.1	15.0	3.1	6.6	9.2	12.1	11.1	24.1	7.3

2.5 Internationalisation in Leading Edge Companies: Home Country vs Host Country Advantages

The above type of analysis has been criticised for concentrating on averages, and thereby missing important changes that may be taking place amongst those leading-edge companies with the most advanced policies and practices in the internationalisation of their technological activities. In particular, it is argued that the emphasis in internationalised technological activities is shifting from adaptation of products and processes to local market conditions, to the monitoring of host-country strengths in technological developments, and to the full-scale development and commercialisation of products and processes from foreign locations.

For this reason, we have recently undertaken an analysis of the 220 companies with the highest volume of patenting activities outside their home countries (Patel and Vega, 1997), in order to assess the extent to which companies locate their technological activities in a foreign location purely on the basis of the technological advantage of that location or on the basis of such advantage created at home. The main conclusions of this analysis are the following:

- In more than 75% of cases, firms locate their technology abroad in core fields where they are strong at home. In 10% of cases, firms establish technological activities abroad in fields of domestic weakness, in order to exploit the technological advantage of the host country;

- The largest increases in foreign technological activities, especially for chemical and pharmaceutical companies, have been in technical fields where there are complementary strengths between the domestic activity of a company and the host country.

These results suggest that adapting products and processes and materials to suit foreign markets and providing technical support to off-shore manufacturing plants remain major factors in the establishment of foreign R & D activities. They are also consistent with the notion that firms are increasingly engaging in small scale activities to monitor and scan new technological developments in centres of excellence in foreign countries within their areas of existing strength. However, there is very little evidence to suggest that firms routinely go abroad to compensate for their core weaknesses at home.

3. UNDERLYING CAUSES

These gradual rather than spectacular trends in the nature and extent of the internationalisation - not globalisation - of corporate innovative activities cannot be interpreted as a major discontinuity or “paradigm shift”. Indeed, Cantwell (1995) has shown that for some firms (mainly those based in the US and Sweden) the degree of internationalisation of their innovative activities was higher in the 1930s than in the 1970's and the early 1980s. Instead, we shall interpret the observed changes as the consequences of four continuous trends since the foundations of the present international economic system were laid after World War Two. Taken together, they have placed nationally-based linkages between the publicly funded science base and locally owned corporate practitioners under growing strain.

- Liberalisation of international exchanges.
- Uneven rates of national technological development.
- Increasing pressures of competition.
- Increasing range of fields of potentially useful technological knowledge.

3.1 1950s & 1960s: USA Dominant

Table 5 attempts to summarise the effects of these changes. After World War Two, the USA was the technologically dominant power, and this was reflected in the reality of international economic and technological exchanges. The US trade advantage compared to the rest of the world was in technology intensive products, and trade

TABLE 5 CHANGING MODES & MODELS OF WORLD INNOVATION & DIFFUSION

PERIOD & CONDITIONS	GOVERNMENT POLICY FOR S & T IN OECD COUNTRIES	CORPORATE POLICY FOR LOCATING R & D	INTERNATIONAL TECHNOLOGICAL EXCHANGES
1950S & 1960S •**USA DOMINANT** •**FREER TRADE** •**GROWTH OF US FOREIGN DIRECT INVESTMENT (FDI)**	•Fund basic research to provide applicable information for corporate practitioners	•At home. Incorporate innovations in processes and products, esp. exports •Choice between exports, licensing & FDI, depending on product - *not* industry - maturity	•Embodied in US Capital Goods •Disembodied skills to produce
1970S •**SPREAD OF NATIONAL CAPACITIES TO IMITATE & INNOVATE**	•Protect basic research •Protect inefficient national champions.	•Adaptive R & D linked to FDI, licensing, & reverse engineering	•Disembodied skills to improve and adapt
1980S & 1990S •**SEVERAL CENTRES OF WORLD CLASS INNOVATION** •**GROWTH IN RANGE OF APPLICABLE TECHNOLOGIES**	•Stress local advantages of basic research - skills, networks •Basic research to attract world best practice firms •Stress *diffusion* - adopting best practice foreign firms, not *innovation* - inefficient national champions	•Access world centres of technological excellence through foreign labs and networks •Increase range of required corporate competencies	•Multi-lateral exchanges of world class technological skills

liberalisation ensured that US technology was diffused internationally through exports of capital and intermediate goods. The subsequent liberalisation of capital movements widened the channels of international diffusion to include licensing and direct foreign investment, particularly for products whose technology had stabilised, thereby enabling US firms to profit from the lower costs of foreign production. Outside the military and health spheres, the US government's role in technical change was restricted mainly to funding basic research in universities in what was seen as a necessary underpinning of the US system of innovation.

The underlying analytical structures that influenced policy reflected these realities. Vernon (1966) explained US comparative trade advantage by innovative leads resulting from labour-saving innovations induced by relatively high wages, and US foreign investment as "trickle-down" of the production of technically mature products in lower wage regions. The international diffusion of technology was embodied in exports of capital and intermediate goods, and in transfers of production skills. Nelson (1959) and Arrow (1962) employed a one-country model in explaining the major role of the US Government in funding of basic research. They argued that, since the output of basic research is codified information that is costly to produce but virtually costless to transfer and re-use, private funding and appropriation of the results of basic research will restrict the use of basic research below the social optimum: hence public funding of published research is justified on grounds of economic efficiency.

3.2 1970s: New National Capacities to Imitate and Innovate

By the 1970s, the realities of uneven rates of national technological development were beginning to leave these analytical structures behind. It became clear from experience that technical change in catching up countries required more than the transfer of production equipment and production skills. It also required a deliberate investment in improvement-generating activities like quality control, training, production engineering and R & D: hence the growth of adaptive R & D activities associated with direct foreign investment and other forms of technology acquisition (Bell and Pavitt, 1993).

In addition, new national centres of world-level innovation had become established, and began to export technology-intensive goods. Germany and other countries of continental north-west Europe re-established the positions of eminence that they had held before World War Two. Japan - and later in the 1980s, South Korea and Taiwan - emerged as new members of the still exclusive club of world-level innovators.

3.3 Adjusting Public Policies: From Protection to Inward Diffusion

The emergence of these competitors in innovation posed difficult and novel policy problems for the countries that had perceived themselves as world leaders in science and technology - the USA and (to a much lesser extent) the UK. Increasing liberalisation meant that international weaknesses in corporate innovativeness and competitiveness were felt more quickly. The immediate reactions tended to be a protective techno-nationalism to try and keep foreigners away from both domestic basic research and flagging national corporate champions. The same analytical framework that justified public subsidy for basic research in a one-country framework became awkward in a multi-country framework. If the ease of transfer and re-use of the results of basic research justified a public subsidy, it also meant that the knowledge could flow freely and easily in or out of the country. Hence, accusations against foreign competitors - especially Japan - for being "free-riders" not contributing to "the world pool of knowledge" alternated with recommendations to cut back on basic research and to import basic knowledge like the other countries were (apparently) doing. This unedifying interlude came to a close with the growing recognition[12] that the main economic benefits of basic research are not codified knowledge, but - as we have already anticipated in the introduction to this chapter - research skills, problem-solving techniques, and membership of international research networks. In this context, knowledge and its exploitation do not come free or cheap, and Japan and neighbouring countries have invested amply themselves in research training and in establishing international networks[13].

Similarly, the protection of uncompetitive national corporate champions on grounds that included their privileged links with the national science base have turned out to be expensive. Governments in most cases have not been effective through direct

[12] By policy makers and academics. Business practitioners have known better for a long time.

[13] Japanese output of basic research has also been increasing rapidly, in terms both of numbers of refereed papers published and the growing frequency with which they are cited. The same is true for S. Korea and Taiwan. See Lattimore and Revesz (1996)

intervention in transforming inefficient into efficient enterprises[14]. Policies have shifted from the promotion of innovation in nationally controlled firms to the promotion of the inward diffusion of world best practice. As has been pointed out elsewhere, R and D activities are essential inputs to both diffusion (catching up) and innovation (forging ahead)[15]. To be effective, R & D for diffusion must be closely coupled to foreign sources of knowledge and technique through such commercial channels as licensing, purchases of capital goods, inward direct investment, and participation in international supply chains (such as OEM agreements)[16]. R & D related to innovation must in addition forge close and flexible links with the latest advances in public knowledge and techniques emerging from the basic research in local universities.

These somewhat differing inputs required for innovation and diffusion were recognised back in the 1960s by Vernon (1960, 1966) in his analysis of causes of business agglomeration in New York City in the late 1950s, and later reflected in his classic and influential paper on the product cycle and international trade. The difference between the first stage of the product cycle (innovation) and the second stage (diffusion) is that, in the first stage, the product and process parameters are not fully understood and fixed, so that flexible and personal links are required, both within the firm between its functional departments, and outside the firm with potential providers of knowledge, complementary inputs, etc. In the second and later stages, parameters are better understood and defined, so that the international transfer of knowledge related to production becomes easier[17]. In other words, national systems of innovation are in fact made up of two, closely related elements: "national systems of diffusion" and "national systems of innovation", narrowly defined. Over the past thirty years, "national systems of diffusion" have been re-inforced in their effectiveness by the growing liberalisation

[14] There were exceptions like telecommunications in France in the 1970s.
[15] See Cohen and Levinthal, 1989
[16] See Hobday, 1995, Arundel et al., 1995.
[17] In the context of this paper, we are applying the product cycle concept to a product *model* (e.g. VOW Golf), and not to a product *class* (e.g. automobiles). For the former, the product cycle concept is empirically well grounded. For the latter, its validity can and is questioned. Lack of clarity about the unit of analysis for the product cycle continues to cause enormous confusion.

of international trade and investment. At the same time, the consequent increase in competition, coupled with the progressive spread of technological activities to a wider range of countries, has put "national systems of innovation" under strain.

Policies favouring inward diffusion at the expense of nationally based innovation were initially pursued most vigorously by the UK Thatcher Governments of the 1980s in the automobile industry, where all large-scale producers are now foreign owned[18]. Similarly, in the electronics industry, government protection for defence and telecommunications equipment was reduced and foreign companies encouraged to enter the UK market. The consequences have been a loosening of the links between the national science base, on the one hand, and both large UK owned firms and the UK production activities of foreign owned firms, on the other. Instead, links have strengthened between the UK science base, and both small UK based firms and foreign firms with R & D activities in the UK[19]. These small, R & D performing UK based firms have specialised in international niche markets like application software, automobile design consultancy and Grand Prix racing cars, very often feeding into the R & D activities of foreign firms in foreign countries.

[18] Some other European countries were slow to follow similar policies, even accusing the UK of being a “Trojan horse” allowing US and Japanese competitors easy access to the European market. But even the French Government recently welcomed a large investment by a Japanese automobile company.

[19] The major corporate contributions to basic research in solid state physics at the Cavendish Laboratory in Cambridge come from foreign owned companies.

3.4 Adjusting Corporate Policies: in Search of Global Excellence

The advantages to business firms of physical agglomeration of R & D activities, and of close linkages to the national science base, are overwhelming for the launching of major innovations. Yet, as we have seen in section 2.5 above, large firms are increasingly locating some of their foreign R & D activities in fields of local technological strength rather than as a support for local production in fields of technological weakness[20]. This tends to happen when firms cannot create all the conditions necessary for launching major innovations in their home base. In part, this reflects the increasing range of potentially useful technologies that large firms need to master (Granstrand et al., 1997), so that the public science base cannot guarantee to provide the required skill and knowledge in all the important emergent fields with equal effectiveness - a problem that first affects large firms based in small countries. In part, it reflects institutional rigidities within the public science base.

In Japan, for example, the national science base cannot at present meet satisfactorily all the requirements of Japanese high technology firms. In spite of the rapid growth of Japanese scientific output and increased funding, institutional reforms (like the introduction of project and programme funding judged by peers) are required in Japanese universities, in order to increase creativity. In the meantime, Japanese firms have been developing world networks, involving the establishment of small but high quality laboratories near world centres of excellence. Similarly, German firms in the chemical industry established strong links with major US research in molecular biology and related medical fields, given the backwardness of the national science base in this field.

In both these cases, the long term expectation is that the knowledge and skill learned in foreign countries will be transferred back to the home country, mainly embodied in

[20] See also Gerybadze and Reger, 1997.

trained researchers. In the meantime, reforms of the science base in the home country will improve its usefulness to local firms. Japanese science is increasing its overall share of the world's papers and citations (Lattimore and Revesz, 1996). German public research in biotechnology has improved considerably (Sharp and Momma, 1997). It is expected in both cases that a "system of innovation" will be restored that links the national science base with national firms.

Such policies often are not feasible for large firms based in small countries, which often can find neither domestic sources of the specific skills they require, nor advanced users to test their major innovations. As a consequence they establish foreign R & D not for purposes of local market adaptation, nor for monitoring and networks, but to develop families of products in a specific field for sale in world markets. The location of such activities is heavily influenced by the local availability of the required skills and knowledge[21]. This explains the high share of foreign innovative activities of large firms based in the Netherlands, Sweden and Switzerland, as well as the high proportion located in regions with similar technological strengths. Whilst this international spread of corporate R & D activities overcomes the constraints of size of the national system of innovation, language and mobility barriers decrease corporate flexibility to re-deploy and re-combine person-embodied skills and resources in the light of changing technological opportunities.

4. CONCLUSIONS

A national system of innovation in which a strong national science base is coupled to innovative, competitive and often large national firms has many attractions. For the public policy-maker, it maximises national returns for public and private investments in

[21] Thus, one of the examples cited by Solvell (1997) is Nestle, who has located its home base for pasta in Italy, and for candies (sweets) in Great Britain.

R & D, in terms of efficiency and competitiveness. For the corporate manager, it reduces the considerable difficulties of managing the development and commercialisation of major innovations across national boundaries. This is enough to explain both the observed persistence of the strong links between national scientific and national technological performance, and the observed low level of internationalisation of innovative activities compared to other corporate functions. However, national systems of innovation thus defined are coming under increasing strain, because a combination of factors - liberalisation, uneven rates of national technological development, and the increasing range of technological skills that firms must master - are creating imbalances or mis-matches between the publicly funded science base and the corporate champions that they have served. Two broad categories can be identified.

In the first, uncompetitive national firms cannot sustain their demands on the public science base, which comes to be linked increasingly to the demands of foreign firms, either through their locally established R & D and related activities, or through their requirements for high technology components, sub-systems and services. This has happened in the UK automobile and electronics sectors over the past twenty years. It is an outcome that is less preferable than strong British firms linking effectively British automobile design and solid state physics skills to product developments for mass markets. But this was not feasible with British based firms in the past, and will be feasible in the foreseeable future only with foreign controlled firms. In the meantime, the research of Mason and Wagner (1997) shows that the present de-coupled and messy British innovation system in the electronics industry is economically more rewarding than the more tidy but inefficient one of the past.

In the second category, national public science systems are not always able to provide the skills and knowledge that national innovating firms require. In some instances - as we saw for Germany and Japan - the internationalisation of corporate R & D will be seen as part of the remedy to improve the national science base. In others -especially firms from smaller countries - substantial internationalisation of R & D will be a permanent part of the solution, even if it does reduce the flexibility to re-combine resources in the light of new opportunities.

Finally, we must point out that the ad hoc nature of our analysis reflects the weaknesses of the analytical structures on which they might be based. A theory of public expenditure on the science base that assumes just one country, and that knowledge is information, no longer helps very much. Nor do the recent insights of the new growth theory, which stress the differences in knowledge externalities - or spillovers - in explaining differences in national rates of growth. The practical implications of this approach are that governments should fund activities with lots of externalities - like academic research and related training. But historical experience gives scant support to such a policy. Britain's substantial lead over Germany and Japan in the 1960s in academic research did not lead to faster rates of technical change and manufacturing growth. On the contrary, Germany and Japan caught up with and overtook Britain in technology; and the former now has done so in science and the latter is catching up.. This experience if anything supports the reverse causality - first proposed by de Tocqueville and Marx - that dynamic capitalists generate more local demands for knowledge and skills than do undynamic ones. The problem is that - on the basis of the past record - most governments do not know how to transform undynamic capitalist firms into dynamic ones. Certainly, the US experience shows that massive government subsidies for defence and health R & D did create positive externalities in the form of major commercial technological opportunities in semiconductors and biotechnology. But these owed less to the foresight of the US Government and to its acquaintance with the ideas of the new growth theorists, than to the US public's fear of communism and cancer.

In these circumstances, we can offer only two tentative conclusions about the future[22]. The first is that national systems of innovation will increasingly involve linkages between the local science base and foreign firms. The degree to which these links will grow beyond monitoring and training activities into local product development and commercialisation remains unclear. Second, the relative growth of international corporate linkages to foreign centres of scientific and technological excellence - as compared to those related to local adaptation and "trickle down" - may help to explain the increasingly specialised patterns of national technological activities (Archibugi and Pianta, 1992). By themselves, foreign corporations are unlikely to create new world-class centres of technological activity.

[22] For similar reasoning, see Cantwell (1998).

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