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Technological Change, Industry Structure and the Environment[♣]

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Abstract

The patterns of production and trade arising from technological changes will have important implications for the future state of the environment, especially concerning greenhouse gas emissions (GHGs). This paper is an output of the UK Tyndall Centre's *E-Tech* project which is seeking to construct an Economy-Energy-Emissions model that incorporates what is known about the evolution of technologies and their locational implications over timescales for 5 to 100 years. The paper takes further the comments of the IPCC (2000) 'Special Report on Emissions Scenarios' (SRES) that "Economists and others who study technological change have developed models that take a variety of dynamics into account… Some models focus on technologies themselves, for example, examining the various sources of "increasing returns to scale" and "lock-in"… Other models focus on firms and other decision-makers, and their process of information assimilation, imitation, and learning… Few of these dynamics, apart from "increasing returns to scale", have been applied to the projection of GHG emissions from the energy sector" (p.141).

In attempting to incorporate insights from theories on the dynamics and evolution of technologies, there are important points to make about: the emergence, development and decline of different sectors/industries, the location of industry and patterns of trade.

The concept of technology we use (as does SRES) is not one where firms and countries can produce and use innovations by dipping freely into a general "stock" or "pool" of technological knowledge. Rather, innovation activities should be seen as *firm-specific, local* and *cumulative.* These processes - change in main branches of production, shifts in geographic structure of production and trade - have important effects on the environment through emissions from production and transportation, which will differ by country and region.

The paper describes a *method* in which the different sectors of the economy can be evaluated on their likelihood of being affected by those 'pervasive' technologies that might change the level of GHG-emissions in the sectors in two time periods: 2000-2020 and 2020-2050. Sectoral classification is based on *Pavitt's taxonomy of sectors* as modified to include service sectors by Miozzo and Soete.

We report the first results of the application of the method, examining both the likely impacts and the regional implications of those impacts of three technologies - Information Technology, Biotechnology and Nanotechnology - that are likely to have the most pervasive influence over the next 50 years.

1. Introduction

The patterns of production and trade arising from technological changes are bound to have important implications for the future state of the environment. This is especially the case with regard to greenhouse gas emissions (GHGs). This paper is part of an ongoing project that seeks to construct an Economy-Energy-Emissions model that incorporates the likely developments in technological change and their environmental implications over timescales of 5 to 100 years.

The paper takes further the comments of the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (Nakicenovic and Suart 2000) that:

> "Economists and others who study technological change have developed models that take a variety of dynamics into account… Some models focus on technologies themselves, for example, examining the various sources of 'increasing returns to scale' and 'lock-in'… Other models focus on firms and other decision-makers, and their process of information assimilation, imitation, and learning… Few of these

> dynamics, apart from 'increasing returns to scale', have been applied to the projection of GHG emissions from the energy sector” (p.141).

This paper extends the work of the IPCC, by considering the insights from students of technological change on the evolution of technologies that are not directly concerned with energy generation or efficiency and their effect on the environment. The dynamic and evolution of these 'non-energy technologies' are not discussed in the IPCC report.

The concept of technology we use is not one where firms and countries can produce and use innovations by dipping freely into some general globally available ’stock’ or ‘pool’ of technological knowledge. Rather, we see technological innovation activities as, if to different degrees, having four features; namely:

- innovations are *firm specific,* emerging from those particular combinations of knowledge, capital and market power that individual firms exhibit,
- innovations are *localised,* with firms ‘searching’ for alternative innovations according to their existing production techniques and organisation, using rules of thumb and proximate targets,
- innovations are *cumulative,* firms learning from the operation of complex systems, and successful innovation usually (but not always) building on previous successes, and
- innovations are *appropriable,* with significant differences between sectors in the importance of the various ways of protecting innovations.

In attempting to incorporate insights from the theories of the dynamics and evolution of technologies, there are important points to make about four aspects of economic activity: the emergence, development and decline of different sectors/industries; the location of industry (and subsequent country specialisation); industry structure; and patterns of trade. These processes, such as changes in main branches of production (e.g. from ‘polluting’ goods handling industries to ’clean’ information handling industries (Castells, 1996)) and shifts in geographic structure of production and trade (e.g. the pattern of trade of machinery and equipment between developed and developing countries (Panayotou, 2000)) have important effects on the environment through GHGs emissions from production and transportation; though these will differ by country and region. These differences in environmental effects by regions and countries are important to capture, given the popularity of proposals for trade in pollution rights, for example.

In this paper, we seek to identify the impact of the development of pervasive technologies on the production of a range of sectors and the consequent effects on their industrial GHG emissions. The sectors are selected according to their technological characteristics. The classification we use to consider the sectoral effects of technological change is based on Pavitt’s taxonomy of sectors (Pavitt, 1984), modified to include service sectors by Soete and Miozzo (1989) (see also Miozzo and Soete, 2001). Pavitt (1984) argues that patterns of innovation are cumulative and that the technological trajectories of innovating firms are largely determined by what they have done in the past as well as their current principal activities. Pavitt differentiates between ‘supplier dominated’ sectors, ‘production intensive’ sectors – subdivided into ‘scale intensive’ and ‘specialised equipment suppliers’ – and ‘science based’ sectors. These generate different technological trajectories determined by sectoral differences in three characteristics: the source of the technology used, users' needs and the means of appropriating benefits. The sectors differ as to whether technological change is product- or process-centred, internally or externally generated, radical or incremental in nature; there are also differences in the methods of appropriation of innovation, and technological diversification of innovating firms.

Whereas Pavitt’s (1984) taxonomy classified services as supplier driven, Soete and Miozzo (1989) show that innovative practices in services can be fitted into a slightly modified set of categories. Service sectors, like manufacturing sectors, can be categorised as ‘supplier dominated’ sectors, ‘scale-intensive’ sectors (which can be further sub-divided into ‘physical networks’ and ‘information networks’) and ‘specialised suppliers and science based’ sectors.

Table One shows the Pavitt/Soete & Miozzo (P/S&M) classification, into eight sectors, with examples of core sectors. This paper will assess the impact of technological change on the structure of production of these PS&M sectors in terms of changes in production scale and in resource intensity, asking such questions as: will pervasive technologies lead to an increase or decrease in production and by what magnitude?, and, as a result of the application of pervasive technologies, will production techniques be more or less resource intensive and by what magnitude?

[insert Table One]

The paper describes a qualitative method to assess the impact on the structure of production of different sectors of the economy of pervasive technologies that might change the level of GHGs emissions in the P/S&M sectors up to 2050. The paper does not try and quantify the effects of technological change on the level of industrial GHG emissions but does suggest the likely magnitude of the effect (large decrease, decrease, no change/negligible, increase, large increase).

The paper is structured as follows. The next section describes the methodology by which the technologies likely to become prevalent during the first half of the twenty-first century were assessed. It draws on the concept of 'long waves' (or Kondratieff cycles), in which each economic wave is marked by a key cluster of technologies, the development of which is accompanied by the establishment of an appropriate and supportive structure of institutions (which together have been called the 'techno-economic paradigm') and which drive economic growth. Then the paper reports the results of the application of a method to assess the impact of developments in three pervasive (‘general purpose’) technologies on the resource intensity and structure of production across examples of industries from the eight P/S&M sectors in terms of their GHGs emissions up to 2050. A final section draws implications for future work in this area.

2. Methodology

To assess the likely effects on the production systems of technological change over the next 50 years, 'long-wave’ theory points to the need to identify the key elements of future ‘techno-economic paradigms' (Perez, 1983). These key elements would be significantly different from those in current paradigms and affect inputs, cost structures and the conditions of production and distribution (Freeman and Perez, 1988). The key elements are also associated with a ‘cluster’ of inter-related radical and incremental innovations (product, process, technical, organisational and managerial innovations) that have a so-called 'pervasive' effect throughout the whole economy. We know that the key elements of all previous Kondratieff cycles developed in the techno-economic paradigm that preceded each one. This suggests therefore that we might be able to identify the key elements of future paradigms within industries that are in their infancy today.

The fifth Kondratieff cycle, the current long wave that began in the 1970s/1980s, is built on the core technological input of microelectronics. One can identify the new infrastructure (telecommunications and the internet), carrier branches (computers and software) and associated organisational changes (such as ‘network’ firms) and other features of national systems of innovations derived from this key input (Freeman and Louca, 2001). The key factor involved in this information and communication technology (ICT) Kondratieff wave will not be superseded until it (and its cluster) shows distinct signs of diminishing returns and limits to productivity growth.

Reviewing the technology forecasting literature (see, for example, Coates et al. 1997), we can already guess which technologies are going to be important in the next Kondratieff wave. Biotechnology, for example, had its roots in 1960s biomedicine (Sharp, 1994) but the biotechnology industry has been growing rapidly and biotech firms becoming financially stronger through the 1990s and into the 2000s. In 2000, for example, US biotech firms raised $33bn on Wall Street (more than the previous five years combined) and remained fairly unscathed by the global downturn with the AMEX biotech Index outperforming the Nasdaq composite and Dow Jones Industrial Average between July 1999 and June 2001 (Ernst and Young, 2001). Interestingly, as internet firms (measured by the AMEX Internet Index) dependent on the manipulation of information, fell by 39% over the two years to June 2001, biotechnology companies (measured by the AMEX biotech Index) increased by 177% (Ernst and

Young, 2001). Biotechnology has the potential to create many generic platforms and have a pervasive effect across a wide range of industries: pharmaceuticals, health care diagnostics, agriculture, food, materials technology, energy, and environmental monitoring (DTI, 2000a). Characteristic of an industry in its infancy, most economic effects are concentrated on the supply side as the core science is developed and the key technologies mastered (DTI, 2000a). There are many overlaps between biotechnology and information technology; without the mature ICT system facilitating distributed working for product development, biotechnology could not have grown so fast.

Nanotechnology is also a fledgling technology that has had its birth within the ICT wave.[1] Developments during the 1980s and 1990s have led to significant government funded projects in the USA and other developed countries (e.g. the creation of the US National Nanotechnology Initiative in 2000 has meant that nearly half of global nanotechnology funding is provided by the US government (Stix, 2001)). Also, some big spending research companies, such as Hewlett Packard, IBM and 3M, are currently devoting one third of their research budgets to nanotechnology (New Scientist, 2001). Developments in nanotechnology could maintain the ICT revolution beyond Moore's Law, increasing chip performance through 'nano-manufacturing' using novel materials such as nano-tubes. Nanotechnology could facilitate biotechnology developments through the application of nanocomputers, for example, to understand better the structure and workings of the biological cell. Nanotechnology might also have an impact on all areas of manufacturing, using nanoparticles to improve basic material properties (Stix, 2001). Nanotechnology's most pervasive impacts seem some way off, most likely after 2050; nevertheless, one can point to early developments in nanofabrication, nanoelectronics and nanomedicine that will impact upon some of the P/S&M sectors before 2050. For example, Taiwan's Ministry of Economic Affairs estimates that the use of nanotechnology in Taiwan's chemical and pharmaceutical industry is expected to create US$180 billion and US$100 billion in production value annually by 2003 respectively (www.fuelcelltoday.com accessed 17 September 2001). Taiwan also estimates that within 10 years the use of nanotechnology in materials and manufacturing processes is expected to create US$340 billion annually and US$300 billion annually in electronic semi-conductor industry applications through improved display monitors, optical storage, fuel cells, memory chips and other electronic components (www.fuelcelltoday.com accessed 17 September 2001).

Based on our current understanding of the role of technological change in economic development in the long term, it is reasonable to assume that, during the next 50 years, the most significant

[1] Nanotechnology can be defined as a technology dealing with materials and systems that have three properties: at least one dimension of between 1 to 100 nanometres (a nanometre is 100 billionth of a metre), designed through a process that exhibits fundamental control over the chemical and physical

technological developments will be energy technologies, biotechnologies, information technologies and (to a lesser extent) nanotechnologies. Existing modelling work includes changes in emissions brought about by the introduction of new energy technologies (e.g. see Nakicenovic and Suart, 2000); but the impact of other technological changes, and in particular the impact of the other three pervasive technologies (biotechnologies, information technologies and nanotechnologies, or as we will call them, the BIN technologies), has not yet been estimated. During September 2001, we co-ordinated a workshop involving a panel of experts from UMIST and Manchester University.[2] The participants involved were experts on the role of technological change in economic development; some had an awareness of climate change issues and experience of scenario-based analysis. Prior to the event, the authors provided the participants with notes explaining the aims of the workshop, the industrial aggregation into the eight P/S&M sectors, an indication of current GHGs emissions of the different sectors and assumptions regarding the technologies likely to be pervasive over the next 50 years.[3] Participants were first asked to identify the most pervasive technologies in the next 50 years and then consider their impact on changes in the structure of production and consequently on GHGs emissions.

The first question considered by the group was whether classifying the relevant technologies into the BIN categories would capture appropriately the expected future dynamics of technological change. Materials technologies, for example, are historically one of the most pervasive, though it is difficult to attribute developments in materials technology to any one technology or sector, particularly when there has been considerable convergence between technologies and when the trajectories of mechanisation and automation are different across industries. For example, there are materials technologies being developed using knowledge and applications of biotechnology (e.g. in the application of genetic modification technologies to the production of biomass for energy, food and chemicals and nanotechnology (e.g. carbon nanotubes) in addition to developments outside of the BIN categories (e.g. memory plastics). Thus, a slightly different classification was suggested focusing on the trajectories of knowledge development that underlie the emergence of specific technologies. Thus, likely technological developments of the next few decades are likely to be concerned with three manipulations: of organisms, of information and of materials. Developments in what we currently call biotechnology are an expression of developments in organism manipulation, though they include the rapidly developing scientific areas (and the technologies that might emerge from these) of

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attributes of molecular scale structures, and capable of being combined to form larger structures (Scientific American, 2001).

[2] The method, best described as 'open Delphi', a structured exchange between a panel of experts which seeks consensus but does not force it. This type of method had been previously used by the Centre for Research on Innovation and Competition (CRIC) as part of a DTI study into 'success' in the field of biotechnology and information and communication technologies in the UK by 2005 (see DTI, 2001a, 2001b).

[3] Disaggregated across the SIC sectors, and aggregated into the eight P/S&M sectors, UK carbon dioxide emissions figures were given from 1998.

genomics, proteomics and metabolomics. Similarly, nanotechnology, to differentiate its effects from information technology or biotechnology materials, should be seen more in terms of 'micro-engineering' materials manipulation.

To sum up, the experts agreed that up to 2050, the most pervasive activities will be in organism, information and materials manipulation; but these manipulations will express themselves at different times in different technologies, most immediately called biotechnologies, information technologies and nanotechnologies, though there will be others in the future that are not currently embraced by these names. The next section examines the impact of these technologies on changes in the structure of production and GHGs emissions.

3. Assessing the impact of BIN technologies on the P/S&M Sectors to 2050

This section explores the impact of the BIN technologies on GHGs emissions in the different sectors. For that purpose, we aggregated the different industrial sectors of the economy, as classified by the Standard Industrial Classification (SIC) codes, into eight P/S&M sectors. Global data on output and CO_2 emissions was available for 18 sectors from the Global Trade Analysis Project (GTAP) Version 4 Database.[4] The 18 GTAP sectors were an aggregation of 50 industries and we re-categorised them into P/S&M sectors.[5] Data from the GTAP database is presented for seven global regions (see Tables Two and Three). Where no global disaggregated data were available, this scoping study used UK data, predominantly from the Marshall Report (HM Treasury, 1998) and the Climate Change Draft UK programme (DETR, 2001). Carbon dioxide emissions figures for the global regions were used to approximate total greenhouse gas emissions (CO_2 is the most significant greenhouse gas, accounting, for example, for over 85% of UK GHG emissions). Analysing both output and emission levels data gives us an idea not only of the size of industrial production in a particular country or region but also how ‘clean’ that production is. For example, where output is significantly different across two countries but emissions levels are the same, one can infer that industrial production is ‘dirtier’ in the low output country. Knowing the emissions levels associated with a set output also lets us better predict the likely effect of technological change on production and emissions levels.

[insert Tables Two and Three and Graphs One and Two]

[4] For details of the Global Trade Analysis Project, see www.gtap.agecon.purdue.edu

[5] This may overstate/understate the true values of some of the output and emissions totals for the P/S&M sectors. For example, the actual figures for the SIIN sector are likely to overestimated since they include ‘water’ (the collection, purification and distribution of water) – which should be included in the SDG sector – and ‘dwellings’ (the emissions from dwellings) – which should not be included in the P/S&M sectoral classification.

For the period to 2050, we assume that changes in the industrial structure will be an incremental development of the current structure (i.e. the SIC code industries of 2000 will adequately conform to the industrial structure of 2050). The following sub-sections of the paper take an example from each of the P/S&M sectors and consider the likely effects of technological change in the 'general purpose' technologies and their subsequent implications, in terms of productivity (i.e. resource intensity) and output and their subsequent effect on emissions.[6]

3.1 Supplier Dominated General: Agricultural sector

What we have called Supplier Dominated General (SDG) firms are likely to be found in the 'traditional' sectors of manufacturing, such as textiles, housebuilding, agriculture, energy production, etc. Firms in the SDG sector are generally small, their in-house R&D and capabilities are weak and most innovation stems from equipment and manufacturing suppliers, large clients and government funded research. Technology tends to be appropriated on the basis of professional skills, design, trademarks and advertising. Technological trajectories are focused on cost-cutting to meet the demands of the price-sensitive user. These industries can be described as predominantly mature and are just as likely to be located in developing countries as in developed countries.

The SDG sector is very important in terms of GHG emissions, accounting for 44% of global industrial carbon dioxide emissions (see Graph Two). Emissions from the SDG sector are particularly important in the USA, Central Europe and the former Soviet Union. Most of these emissions can be attributed to the energy production and energy extraction sectors, accounting for 80% of total global SDG emissions. Also important within the SDG sector are the construction and agriculture industries. Agriculture contributes 6% to global CO_2 emissions through practices such as peat and fenland drainage, timber harvesting or conversion of grassland into arable land and is a significant contributor to other greenhouse gases, notably methane and nitrous oxide, which stem from animal digestive processes, animal wastes and fertiliser use. Agricultural output is concentrated both in developing countries (e.g. China, India and other East Asia and Latin America countries) and developed countries (e.g. Western Europe, North America and Japan), though CO_2 emissions are significantly lower in the latter (see Graphs One and Two).

In the agriculture sector, technological change affects production of both food and non-food products. Biotechnology is already beginning to transform the agriculture and food industry, with the production of genetically modified foods (though less so in Europe than in other global regions). Developments in newer organism manipulation technologies, particularly those that draw on rapidly growing knowledge of plant and animal genomes, leading to new food products (e.g. nutraceutical

[6] It is important to note that the 'impacts' of technological change in all sectors were discussed without

products), new crop management methods (reducing the need for harmful fertilisers and pesticides (DTI, 2000a)) might, in the timescale we are considering, win over currently sceptical public opinion and lead to increased production of more 'biotechnology'-based foods.

In non-food agriculture, biotechnology is also likely to play a significant role over the next fifty years; for example, in wood-related innovations such as faster growing methods, and cell cultures to grow wood and fruits in alternative locations. The impacts of these developments may lead to change in the site of production and impact on bio-diversity (with as yet unknown effects) and the consumption of other materials due to substitution effects. As with food production, the less-energy-intensive developments in organism manipulation may replace conventional chemical production.

While future biotechnologies could fundamentally change the cultivation process of food and non-food produce, developments in information technologies and nano-technologies could significantly affect the harvest (reaping) process. These developments may have different effects in different parts of the world. For instance, developments in and the increased diffusion of information technologies may lead to more energy-intensive production in developing countries through, for example, increased mechanisation in agriculture. Conversely, progress in nanotechnology and materials manipulation (particularly nanofabrication and nanoelectronics) will play a major role in producing more energy-efficient harvesting equipment (incorporating lighter, smarter materials) for use in developed countries. Also, nanometre scale engineering might be employed (nano-structured alloys and composites, advanced functional polymeric materials) to create novel functional and structural materials of superior performance (EC, 2001).

The impact of technological change in organism manipulation in the agricultural sector also has the potential to transform sectors beyond the agriculture industry as a result of improvements in biomass. There will be increased demand for the production of certain crops if biomass realises its potential and we move toward a more 'carbohydrate economy' (e.g. if cost reductions in industrial enzymes enable plant extracts to be used in the production of high quality-low cost industrial products). Other downstream growth sectors, using products from a biotechnology-boosted biomass industry, may include food, pharmaceuticals, textiles, construction, chemicals, fuels and fertilisers.

In summary, if we consider both food and non-food agriculture, resulting from the advanced manipulation of organisms (in particular), output from the agricultural sector is likely to increase quite significantly over the next fifty years in both developed and developing countries. Higher production in the SDG sector will lead to higher GHG emissions, the extent of which is driven largely by

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assuming any adaptation by the system to the effects of climate change.

locational aspects of the diffusion of advanced information and materials technologies. The associated effect on GHG emissions are likely to be negligible in the developed world but large in the developing countries, particularly in China, India and other East Asian and Latin American countries.

3.2 Supplier Dominated Services: Health and Education

Supplier Dominated Services (SDS) firms can be divided into providers of personal services (e.g. restaurants, hotels) and public/social services (e.g. health, education and defence). In general, firms in these sectors make only a minor contribution to their process technology; any innovations that they introduce are embedded in or stem from equipment, information and materials provided by manufacturing sectors. The technological trajectories of the two types of SDS firms are governed by the type of user, performance-sensitive for personal services and quality-sensitive for public, and innovations are geared toward (service) product design and improving performance.

Output and emissions are considerably smaller in the SDS sector than in the SDG sector, constituting nearly 9% of global output but less than 4% of total CO_2 emissions in 1995 (see Graphs One and Two). Health and education services are probably responsible for the largest GHG emissions across the SDS sector, for example contributing over half of the sector's total CO_2 emissions in the UK. The output of the SDS sector is by far the greatest in Europe (particularly Germany), the USA and Japan. However, the delivery of services in these areas is relatively energy efficient; emissions in China, the former Soviet Union (FSU) and Northern Africa are equivalent to those in the USA despite output being significantly smaller.[7] Emissions can be attributed to the delivery of health and education services, especially from hospitals, GP surgeries, schools, government laboratories, etc. This includes all energy-related costs incurred throughout the life cycle of buildings (maintenance, heating and lighting, etc) and from the operation of capital housed inside the buildings (e.g. in the health service, intensive-care machines, operating theatres etc).

Developments in BIN technologies are likely to affect the minimum efficient scale and move sectors toward the point of consumption, particularly with the wider diffusion of communication technologies. Improvements in medicines through biotechnology advances are likely to be reflected in increased demand for advanced medicines. Information and communication technologies are likely to lead to increased decentralisation with internet-based/virtual health care and education provision. For example, virtual TV-based self-diagnosis technology could increase resource efficiency by reducing demand for GPs (and hence surgeries). Information technologies will lead to increased awareness of treatments through internet advice. Developments in organism manipulation may increase the chance

[7] For instance, according to GTAP data, output from the SDS sector in China in 1995 was equal to US$8.09bn compared to 145.68 US$bn in the USA. CO_2 emissions in the two countries were 0.08bn tonnes and 0.091bn tonnes respectively.

of preventing (rather than curing) disease, requiring more, cheaper healthcare provision earlier rather than more expensive treatment later; perhaps this emphasis on preventive medicine might break the tendency for curative medical advances to increase demand for treatments. Putting to one side the potential developments that may result from biotechnology conducted at the nanoscale (such as increasing the speed of biomedical tests), advanced materials manipulation could create the nanodevices both to facilitate the creation of ICT-based self-diagnosis equipment and to help combat disease effectively. Future nanotechnologies will also help combat disease with improvements in detection, diagnosis and treatment; for example, imaging using new or improved contrast agents may be able to reveal tumours only a few cells in size, nano-particles could 'deliver' treatments to specifically targeted sites, nanometer scale modifications of implant surfaces could improve durability and biocompatibility (Alivisatos, 2001). These developments could enhance resource management and resource efficiency in the health sector. These advances could also be applied to the education sector, through the personalised access to, and delivery of, advanced learning workplaces in schools, universities, the workplace and homes (EC, 2001). Advances in information technologies will improve administration, offering a small efficiency increase but they would also increase the volume of energy-using equipment.

The resulting balance of the scale effects associated with the growth in output (and hence energy consumption) on the one hand and the expected improvements in energy efficiency on the other, is not clear. Manipulations of information, organisms and materials are likely to increase output whilst (particularly the latter two) also contributing toward lower resource intensity. In developed countries, output increases as a result of technological change are likely to offset by improvements in resource efficiency leading to lower GHG emissions. Very high growth in output in the developing countries, coupled with lower resource intensity gains, will give large increases in GHG emissions over the next fifty years.

3.3 Scale Intensive General: Chemicals

The Scale Intensive General (SIG) sector is made up of those industries, for example in the chemical, electrical goods and motor vehicle industries, that provide bulk or assembly products. Important sources of process improvements come from the production engineering departments and from small-specialised external companies that supply the specialised machinery (see section 3.4). In-house engineering departments focus on improving the performance of complex integrated production processes – identifying and correcting imbalances and bottlenecks to improve productivity. Technological advances are reflected in the efficient continuous running of large-scale integrated production processes to produce a final good and are protected through in-house know-how, secrecy and patents.

The SIG sector is the largest P/S&M sector in terms of global output but it is significantly 'cleaner' than the SDG sector, contributing just over one quarter of global CO_2 emissions (see Graphs One and Two). Production in the SIG sector is highest in most developed countries and is especially important in Japan – in contrast, output in the SDG sector is higher, for example, in developing countries within Central Europe, the former Soviet Union and Asia. SIG output is concentrated in the food and chemicals industry and emissions are associated with their energy-intensive production processes. The ferrous and non-ferrous metals industry is another significant industry in the SIG sector in terms of CO_2 emissions, despite its relatively low output. Output in chemicals is dominated by Europe (and Germany in particular), the USA and Japan; however emissions are relatively low. The largest polluters in the chemical industry relative to their output are producers in Central Europe and the Former Soviet Union and Asia (and China in particular).[8] Chemical industry production covers the spectrum from low value-added bulk chemicals to high value-added low volume chemicals; from organic chemicals to dyes and paints and highly sophisticated speciality products for the pharmaceutical and agrochemicals industry (Sharp, 1994). The large chemicals firms provide products across this spectrum, arguably operating in two different markets: a concentrated organic chemicals mature market and a fiercely competitive specialised chemicals growth market. Therein lies the distinction between the likely effects of technological change. Within the chemicals sector there is likely to be decreased demand for bulk chemicals and increased demand for specialist (less mass-produced and more energy-intensive) chemicals.

Future manipulation of organisms will be particularly important in terms of agrochemicals and specialised chemical products and the chemical multinationals are likely to devote departments to organic manipulation science or buy up dedicated biotechnology firms, increasing sector output. New dedicated biotechnology firms will also exploit niche markets expanding sector output. Developments in organism manipulation may also improve environmental waste treatments, increasing the output of biotechnology based environmental processing methods (DTI, 2000a). As referred to above, wide availability of cheap industrial enzymes may facilitate the production of high quality-low cost industrial products from plants (such as degradable plastics and foams from maize and soy oil).

As output increases through advances in biotechnology, developments in information and materials manipulation are likely to lead to increased resource efficiency in the production of chemicals, particularly in developed countries where we could see a very significant reduction in GHGs (with a

[8] For instance, although emissions of CO_2 are similar in China and Japan (both produced 0.142bn tonnes of CO_2 emissions in 1995), output in Japan was nearly five times greater than in China (US$52.57bn and US$10.96 respectively).

less significant reduction in developing countries). Developments in the manipulation of information (e.g. improved sensing devices) should result in better monitoring of industrial processes, allowing firms to eliminate waste and use capacity more efficiently (Leadbetter and Willis, 2001). Also, nano-machines may provide valuable tools for chemical synthesis and sensing devices (Whitesides and Love, 2001).

In summary, the effects of technological change, particularly in the manipulation of organisms, will increase output of SIG industries. However, advanced materials and information technologies will increase resource intensity and overall, in the developed countries, there is likely to be a negligible effect on GHG emissions. In the developing countries, output growth will be large, dwarfing gains in resource intensity and resulting in a large increase in GHG emissions.

3.4 Specialised Supplier General: Instrument engineering firms

The Specialised Supplier General (SSG) sector includes firms that, despite producing a relatively large proportion of their own process innovation, are a major source of innovation for other larger firms, including, for example, those in the SIG sector, complementing innovations sourced from their engineering departments. These firms include mechanical and instrument engineering firms, such as those in machinery production and transport equipment production. These small firms, with specialised knowledge and experience, supply the equipment and instrumentation to the SIG firms and because the cost of poor performance is high, technological trajectories are geared toward providing high-quality performance-increasing product innovation. In contrast to the production engineering departments of SIG firms, external competitive pressures ensures that the appropriation of technology depends on providing a continually improving, reliable product that meets the users' requirements. Compared with the SDG and SIG sectors, output in the SSG is small and production is concentrated in the EU, USA and Japan (see Graph One). Emissions predominantly stem from the production of specialised machinery and instrumentation for external users and SSG firms in these three global regions are not a significant source of CO_2 emissions. Polluting industries can be found in Central Europe and especially in the former Soviet Union, where despite output being nearly 14 times less than in the EU, emissions are greater (see Graph Two).[9]

For firms in the SSG sector, improvements in the product design are likely to be aimed at improving quality and the manipulation of information and materials are likely to have an important impact on product design. The production of sensors are likely to be significantly increased as their potential

[9] In 1995, output from the SSG sector in the EU was US$114.3bn contributing 0.0596bn tonnes of CO_2 emissions. In Central Europe and the former Soviet Union output totalled US$8.26 with emissions of 0.062bn tonnes of CO_2 emissions.

number of applications increase (e.g. through increased automated production) and as their reliability and performance with improvements in the manipulation of information (e.g. more energy efficient production), materials (e.g. less material intensive production) and organisms (e.g. environmental sensors). In particular, there may be advanced production technologies with superior energy efficiency characteristics, through, for example, the integration of information technologies with sensing and control technologies (EC, 2001). Also, from developments in organism manipulation one may anticipate, for instance, increased demand for analytical instruments and sensors (e.g. to detect the presence of proteins and biological contaminants in the food chain) (DTI, 2000a).

Advances in materials manipulation will develop a new generation of instrumentation for analysis and manufacture at the nano-scale, for example, advanced techniques for nanoscale manufacture, such as lithography or microscopy based techniques (EC, 2001; see also Whiteside and Love, 2001). Developments in materials manipulation also have the potential to transform the properties of instruments, both in terms of their tensile strength (e.g. carbon nano-tubes have 60 times the tensile strength of steel) and electrical properties (e.g. different 'twists' built into carbon nanotube's hexagonal carbon lattice and they can conduct or semi-conduct) (Red Herring, 2001b). As production technologies make these products cheaper, carbon nanotubes could be applied widely, replacing silicon chips, their size, strength and electronic versatility allowing them to function in extreme heat and demanding environments (Red Herring, 2001a).

Nano-electromechanical systems (NEMS) have the potential to operate using a millionth to a billionth less power than traditional transistors. This offers the possibility of widespread diffusion of cheap, ultraminiature 'smart' sensors that could continuously monitor all the important functions in hospitals and manufacturing plants (Roukes, 2001). However, the adoption of these nano-devices will require firms to invest in new infrastructure and abandon, for example, semi-conductor processing plants that cost more than US$1 billion (Roukes, 2001).

In summary, output of SSG firms, due to developments particularly in the manipulation of information and materials, is likely to increase as demand for the use of advanced technologies in more productive industrial processes increases. Though the outputs from this sector are likely to lead to increased resource efficiency in other sectors of industry, particularly in the SIC and SDG firms, output effects will probably override increased efficiency in the manufacture of instruments, sensors, etc. Thus, we can hypothesise increased output, lower resource intensity and slightly higher (or negligible) GHG emissions in the developed countries. In the developing countries, the benefits of technological change will be slower to diffuse and higher output is likely to be associated with increased GHG emissions.

3.5 Scale Intensive Physical Networks: Wholesale and Transport

Firms in the Scale Intensive Physical Networks (SIPN) sector are capital intensive, involved in large-scale processes with advanced labour specialisation. The development of the sector has been linked to developments in information technologies with the aim of creating networks and reducing costs. Firms in the wholesale, retail and transport industries are good examples of SIPN sector firms. The SIPN sector is very important in terms of output and GHG emissions, accounting for around 15% of each (see Graph One and Two). Output is dominated by production in the EU, USA and Japan; industries in the first two are 'dirty' but Japan is relatively clean.[10] Heavily polluting SIPN industries (relative to their output) are found in Central Europe and in the former Soviet Union and China in particular. Within the SIPN sector, transport is the over-riding 'dirty' industry, contributing nearly three-quarters of sector emissions in the UK, for example, but retailing and wholesaling activities also contribute 8% and 5% of sector emissions respectively (Marshall Report, 1998). Emissions in wholesale and retail predominantly stem from the building and use of estates (warehouses, shops, etc). Transport encompasses emissions from 'road' (e.g. passenger cars, lorries, vans, buses, etc), 'off-road' (e.g. rail) and 'other' (e.g. aviation, shipping) sources. It is the fastest growing sector in terms of emissions.

Developments in information technologies will have a significant impact on the retail sector, in terms of increased resource efficiency, for example, through greater prevalence of microchips. Developments in information manipulation and materials manipulation will decrease the price of, and increase the demand for, consumer goods. Lower prices, combined with greater access to secure, easy-to-use, computers and networks, as a result of their integration into 'everyday environments', will increase the demand for goods and services purchased both conventionally and digitally.[11] Improved logistics, facilitated through developments in the manipulation of information are also likely to increase the efficient use of resources by, for example, ensuring that distribution and transport networks operate at capacity (e.g. ensuring lorries leaving and returning to the distribution depot are full) (Leadbetter and Willis, 2001). Thus, distribution, waste and capacity efficiencies may be facilitated through information technologies. However, as the volume of goods bought over virtual media increases (e.g. in what is now called internet shopping or TV-shopping), distribution outlets may work continuously to satisfy demand, producing greater emissions through increased operations

[10] Output in the EU, USA and Japan is valued at US$241.2, US$221.9 and US$175.69 billion respectively. However, where emissions from the EU and USA are equivalent to 0.42bn tonnes of CO_2, emissions from Japan are equivalent to 0.093bn tonnes of CO_2.

[11] Developments in information manipulation may also increase the demand for virtual goods (that have no physical manufacture, storage and travel impacts of physical goods). Past evidence shows that the growth of alternative mediums are largely dependent on a consumer culture change and are

and out-weighing the lower emissions associated with fewer shops. In addition, there are likely to be higher emissions associated with more air-freight and more light goods vehicle delivery, plus increased demand for warehousing (James and Hopkinson, 2001). Also, when one factors in the necessary additional transport emissions involved in delivery and increased packaging waste, increased output for the SIPN sector may lead to increased greenhouse gas emissions (Wilsdon, 2001; James and Hopkinson, 2001). There are likely to be different changes in output and efficiency between and within sectors. Developments in information technologies may lead to the creation of merged wholesale-retail-distribution firms, creating niche opportunities for small specialised shops, which are also more likely to be less energy efficient.

The impact of organism manipulation technologies on this sector will not be direct; rather it will be in the materials that are intricately bound up with the networks of material product movement that distribution, retailing and wholesaling put together. So, we might expect new fuels from biotechnologically-enhanced biofuels biomass being widely diffused into transport systems, according to availability and price. We might also see new developments in packaging, using new organic materials, which might alter the total weight of goods moved (and therefore its gross energy usage) as well as reduce the volume and quantity of waste. Through materials manipulation, nanostructured materials could be used to transform the size, weight and propulsion properties of the materials used to make the carriers involved in distribution networks (e.g. lorries, vans), making the distribution process more resource efficient, despite the increased output. Developments in materials manipulation are also likely to facilitate the use of alternative fuels in vehicles.

As a result of future materials and information technologies, there is likely to be increased output in the retail and distribution sector. However, it is also likely that resource intensity will fall. In the developed countries, which effect will be the strongest is difficult to judge and depends greatly on 'transport' issues (e.g. the type of transport used to distribute the increased output from the retail industry, the fuel, etc) and 'consumer' issues (e.g. how consumers react to new, alternative methods of shopping). However, judging by recent trends, it is likely that GHG emissions will increase overall as output increases exceed resource intensity savings. In the developing countries, the result is likely to be less ambiguous with a large increase in output associated with higher GHG emissions.

3.6 Scale Intensive Information Networks: Telecommunications

Firms in the Scale Intensive Information Networks (SIIN) sector are dependent on information networks and can be found in the finance, insurance and communications sector. Innovations are geared toward end-users of the service and may stem from firms in the manufacturing sector. The

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more likely to enhance and complement, rather than displace, the real economy of goods (see

SIIN is a rapidly growing industry sector and is the largest P/S&M sector in terms of output in countries in the EU and USA. SIIN production is also a significant part of the economy in other developed countries: Japan, Canada, New Zealand and Australia for example. However, production of the SIIN firms is relatively 'clean', less energy intensive than manufacturing firms and CO_2 emissions are small in comparison (see Graphs One and Two).[12]

Developments in information technologies are likely to lead to the increased growth of the service sector of the industry, both in terms of its relative contribution to developed countries' GDP and in terms of employment. Information technologies have helped transform the telecommunications industry and further manipulation of information and materials in the future will increase both outputs and resource efficiency. CO_2 emissions from the telecommunications industry stem from the provision of the most advanced and widely available (in terms of coverage) service. Optical improvements from future information and materials technologies will vastly increase capacity and, moving beyond Third Generation (3G) developments, IT advances will contribute toward complete coverage, optimal service connection, allowing global personalised access to networked systems (EC, 2001). Output, productivity and efficiency savings will be facilitated through advanced materials such as nano-optics (pulses of light to increase data through high bandwidth by optical networks – there are already prototypes of 3D micro-electromechanical systems of MEMS switches). The widespread diffusion of these and similar technologies are likely to lead to increased output (increased optical switching production), improved productivity for voice calls and internet data, reductions in time (current switches have to be converted to electrical signals, therefore redirection will be easier), reductions in prices and costs and increased reliability of the network (Red Herring, 2001b). These effects will be seen first in the developed economies but when diffused into the developing countries over the next fifty years are likely to be much greater. In the developing countries the telecommunications companies will have to establish infrastructures suitable to provide a network for service provision. This in itself will involve a large capital intensive, GHG intensive operation.

The impact on the SIIN sector of future developments in the manipulation of information and materials, particularly in the developed countries but also in the developing countries, is set to increase demand for information services greatly over the next 50 years. Emission levels in the developed countries will probably increase as the growth in output will offset improvements in resource efficiency but the biggest changes will be seen in the developing countries. There will be large increases in output and the GHG emissions associated with creating an infrastructure suitable for providing an advanced information network service will increase substantially and are likely to dwarf

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Leadbetter and Willis, 2001).

[12] The actual figures for the SIIN sector are likely to overestimated since they include "water" (the collection, purification and distribution of) which should be included in the SDG sector.

any increases in resource efficiency associated with developments in information and materials technologies.

3.7 Science Based General: Pharmaceuticals

Science Based General (SBG) firms are to be found, for example, in the pharmaceuticals and electronic/electrical sectors. The main sources of technology are the R&D activities of firms in the sectors, based on the rapid development of the underlying sciences in the universities and elsewhere. Successive waves of innovations have been built on the prior development of relevant basic science. This pervasiveness has dictated the technological trajectories of firms in the science based sectors and has meant a wide variance in the relative emphasis on production and process technology. Dynamic learning economies in production have been an important barrier to entry for imitators.

Although no global data is available for the SBG sector, it is reasonable to assume that the sector contributes only a fractional proportion of a country's or region's GHG emissions. For example, in the UK in 1998, the SBG sector accounted for 3% of total gross output and contributed less than 1% to total UK CO_2 emissions (HM Treasury, 1998).[13] We also know that much of this type of production is concentrated in developed countries and can assume that the sector will see significant growth in production over the next 50 years as a result of technological change. For instance, the pharmaceuticals industry is likely to grow rapidly as developments in organism manipulation lead to more pharma-products. Developments in organism manipulation, particularly in genomics, are likely to increase output in pharmaceutical products, including more 'designer drugs'. However, the development time of new products (and resource intensity) is likely to fall as biotechnology expertise grows.

Advanced information technologies will also facilitate the development of new pharmaceutical products, contributing to increased output, increased product differentiation whilst also helping to cut development time and resource intensity of drug discovery. For instance, bioinformatics will be able to apply advanced information technologies to the management and analysis of biological data to solve biological problems (CRIC, 2001). Bioinformatics is particularly important when considering developments in gene sequencing.

Nanotechnologies are also likely to facilitate the success of biotechnology induced designer drugs by, for example, providing very small (less than 100 nanometers) casing for new drugs. Also,

[13] Figures for the SBG sector in the UK are taken from the Marshall Report into "Economic Instruments and the business use of energy" (HM Treasury, 1998) including output and emissions data from the pharmaceuticals (SIC 24.4) and electronics (SIC 30, 32) industries.

nanoparticles may deliver drugs where they are needed and control their release. Developments such as these are likely to increase the output of the pharmaceuticals industry.

In summary, firms in the SBG sector are not significant contributors to GHG emissions. However, higher output stemming from developments in organism (and to a lesser extent information and materials) manipulation will outweigh resource efficiency savings brought about by the latter two technologies, particularly in the developing countries but also in the developed countries. Thus, one can hypothesise increased GHG emissions from the SBG sector over the next 50 years in the developed countries and significantly increased GHG emissions in the developing countries.

3.8 Specialised Suppliers/Science Based Services: Business Services

In addition to pharmaceuticals and electronics science based firms in the manufacturing sector, the 1990s have seen rapid growth in the number of business service firms developing and applying information technologies. Most innovation that stems from R&D conducted by small firms within this sector is concentrated on system design and geared toward improving the performance of the technology users.

Although no global (or UK) data at a sufficiently disaggregated level is available, one can assert that output from the SBS sector is small in comparison to other P/S&M sectors. One can also argue that the sector is likely to grow rapidly over the next 50 years as outsourcing increases and business services deliver state-of-the-art technology to firms across the P/S&M sectors, particularly in agriculture and manufacturing. These services will typically be computer services, management consulting services, especially in human resource management and finance functions. Demand for business services will also increase with growth in the number of firms involved in information processing and those that require high levels of communication between providers and customers. Developments in the manipulation of information and materials will further boost output by improving the performance of software. This increased output will require a developed infrastructure to be delivered but this is not the role of SBS firms – the telecommunications sector will provide future advanced networks.

In terms of GHG emissions, although output will increase rapidly, so too will resource intensity within the sector. Most business services involve the temporary transfer of staff from the customer to the provider. Developments in information technologies may reduce the 'human traffic' between the customer and provider through the application of, for example, virtual technologies and 3D information transfer. Similarly, future information technologies are likely to further collapse time and space at lower costs facilitating global (as oppose to local) provision and consumption of business services. Multinationals' customers will be able to source their business services centrally – probably at the headquarters – and multinationals will behave in a 'hub and spoke' way, providing foreign subsidiaries and affiliates with updated information technologies. Growth in GHG emissions associated with higher sectoral output may also be tempered by information and materials manipulation (e.g. more energy efficient, less material intensive).

In summary, output growth in the SBS sector is likely to be high, particularly when one considers the potential markets in China and other developing nations. GHG emissions will also increase, despite improved energy efficiency. The extent of GHG emissions growth will depend on the prevalence and diffusion of virtual technologies and the degree of acceptance of 'local production, global consumption' business service provision. One can hypothesise increased GHG emissions in both developed and developing countries over the next fifty years.

4. Implications and conclusions

This paper seeks to make a contribution towards the construction and application of a method to assess the long-term impact of the development of pervasive technologies on the environment. As such, it seeks to integrate insights from studies of technology regarding long-term growth with questions of sustainability. Using a methodology based on long-wave theory and an industrial classification based on technological characteristics, the likely effects of three technologies on the production and resource intensity of firms within the eight aggregated sectors on the emission levels of industrial greenhouse gases have been considered. Table Four shows a summary of the results of the analysis.

[insert Table Four]

Two of the most significant sectors in terms of GHG emissions currently – the Supplier Dominated General sector (SDG) and the Scale Intensive General (SIG) sector – are both likely to see increased sectoral output as a result of developments in the manipulation of organisms, information and materials. The contribution of future information and materials technologies in increasing the resource efficiency of these sectors will be significant and the effect on GHG emissions will depend on the magnitude of each effect. Locational aspects will clearly be important for the Supplier Dominated General and Scale Intensive General sectors and it is likely that GHG emissions will either change negligibly or will increase only slightly in the developed countries whilst increasing (sometimes greatly) in the developing countries. Similarly, the trade-off between higher output and lower resource intensity, as a result of developments in information, organism and materials manipulation, will result in lower GHG emissions in the developed world and higher emissions in the developing countries for firms in the Supplier Dominated Service sector. Another big polluter in terms of GHG emissions is the Scale Intensive Physical Networks (SIPN) sector. Here, increased output is likely to more than offset efficiency savings facilitated through future manipulation of information and materials. Starting from an already high level, GHG emissions from the SIPN sector is likely to increase steadily over the next fifty years in both developing and developed countries. The application of information and materials technologies by firms in the specialised Supplier General sector, a sector which is the source of machinery and components for all other sectors, is particularly important in increasing the resource efficiency of production processes of firms in the SDG, SIG and SIPN sectors. For firms within the Specialised Supplier General sector though, increased emissions from increased output is likely to exceed lower emissions from lower resource intensity for the developed countries – a net effect of slightly increased GHG emissions. The developing countries will probably see a net effect of increased GHG emissions as a result of more dominant technologically- induced increased output.

Firms in the Science Based General sector, the Science Based Services sector and the Scale-Intensive Information Network sector are not currently responsible for high GHG emissions. However, these are the three sectors that are, relatively speaking, likely to see the most significant growth in terms of output and GHG emissions in the developed countries but also especially in the developing countries. For Science Based General sector firms, organism manipulation will be very important in creating demand for advanced biotech/pharmaceutical products, though production is likely to remain in the developed countries. GHG emissions are likely to increase, off-setting the application of resource efficient technology. For firms in the Scale Intensive Information Networks and Science Based Service sector, increased output will be based on the advanced manipulation of information and materials. Although resource intensity will undoubtedly increase, the mass unexploited markets of developing countries will increase GHG emissions over and above any gains. One can hypothesise slightly higher GHG emissions in the developed countries and a large increase in GHG emissions in the developing countries.

The method we have described and the (provisional) results we have reported are qualitative. We are currently seeking to develop an extension of the method which will try to quantify the effects of technological change. The collation of time-series data on disaggregated sectoral output and GHG emissions across regions of the globe, and a more explicit consideration of quantifying the likely effects of technological change on emission levels is essential for such an analysis. Future work will also consider the impact of technological change after 2050. This is more hypothetical since one must consider how the structure of the economy will change over the next fifty years – some industries will die and new ones will emerge. However, the conceptual framework laid down in this paper – aggregating industry into sectors according to their technological characteristics and considering the impact of technological change according to output and resource intensity dimensions – should facilitate this process. The starting point for an analysis between 2050 and 2100 could thus be based on the consideration of the impact of the development of technologies on the eight clustered P/S&M sectors that we have described in this paper.

Our findings suggest that industrial policy addressing the development and diffusion of pervasive technologies may have an important role in forging a path of economic growth that can meet the challenge of sustainability from an ecological point of view. The scope of these changes will vary in different countries, but they will have in common, both at national and at firm level, the assimilation and effective use of biotechnology, information and communication technology and nanotechnology. The next step for our research is to assess the long-term effects of these pervasive technologies on the movement of goods, finance and technology between countries. The effects of the development of these pervasive technologies on the patterns of trade, foreign investment and the transfer of technology are likely to have a significant effect on the level of industrial GHG emissions.

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Table One: Pavitt (1984)/Soete and Miozzo (1989) classification of industrial sectors

Category of firm	Typical core sector
Supplier Dominated General ***(Pavitt)***	Agriculture Housing, Traditional manufacturing
Supplier Dominated Services ***(Miozzo & Soete)***	Personal services (restaurants, laundry) Public and social services (health, education)
Scale Intensive General ***(Pavitt)***	Bulk materials (steel, glass), Assembly (consumer durables, cars)
Specialised Suppliers General ***(Pavitt)***	Machinery Instruments
Scale Intensive Physical Networks ***(Miozzo & Soete)***	Transport Wholesale
Scale Intensive Information Networks ***(Miozzo & Soete)***	Finance Insurance Communications
Science Based General ***(Pavitt)***	Pharmaceuticals
Specialised Suppliers/Science Based ***(Miozzo & Soete)***	Software Specialised Business Services

Table Two: Global Output Data by P/S&M Sector 1995 in US$ billion

P/S&M Sector	GTAP Sector	EU15	CEU	NAM	JAPZ	OEC	ASIA	ROWT
SDG	01 Agriculture	41.82987	9.32461	30.74134	27.58101	13.24618	59.53202	46.26056
SDG	02 Coal	3.05885	1.72022	2.86446	0.07217	1.12417	4.72018	0.66746
SDG	03 Oil	18.71363	10.52153	20.60598	9.04858	7.20761	14.50138	43.9078
SDG	04 Gas	10.61989	4.96535	16.03842	9.91684	3.95968	3.50787	7.02507
SDG	05 Electricity	20.333	5.84369	16.6981	15.94094	4.73059	12.54197	12.29461
SDG	13 Construction	104.1801	11.5242	89.83511	94.98537	20.3873	41.92388	32.88109
SDG	16 Textile Industry	34.18626	6.54546	23.44955	21.00049	5.4301	38.58879	25.24247
SDS	18 Non Market Services	195.6379	11.8589	145.6842	47.84981	28.13263	36.16702	51.03992
SIG	06 Ferrous and non ferrous metals	32.58799	6.30593	19.86919	25.14454	7.18177	21.56132	15.10008
SIG	07 Chemical Products	75.42113	7.69724	51.21866	52.56607	13.08874	30.39657	29.36997
SIG	08 Other energy intensive	59.2712	7.72302	41.74447	39.45969	13.65729	23.88251	23.8694
SIG	09 Electronic Equipment	27.79273	3.26365	31.17932	42.03233	3.08115	20.38622	7.59213
SIG	10 Transport equipment	65.30823	3.66682	56.31272	24.29708	11.04536	12.49554	14.39804
SIG	12 Other Manufacturing products	39.78689	3.64462	19.88366	18.68102	6.76564	14.78522	10.2109
SIG	14 Food Industry	83.48803	11.22296	54.04098	54.96207	15.78329	34.09488	46.24312
SIIN	17 Other Market Services	430.1112	22.59975	308.5697	198.3544	55.72682	49.04977	70.57572
SIPN	15 Trade and Transport	241.2007	22.67522	221.9026	175.69	59.29994	85.40998	76.58457
SSG	11 Other Equipment Goods	114.3159	8.26058	73.31166	75.73104	17.56582	45.04015	20.43084

Key:
SDG: Supplier Dominated General
SDS: Supplier Dominated Services
SIG: Scale Intensive General
SIIN: Scale Intensive Information Networks
SIPN: Scale Intensive Production Services
SSG: Specialist Supplier General

EU15: European Union
CEU: Central Europe and FSU
NAM: USA
JAPZ: Japan
OEC: Other Europe Canada Australia and New Zealand
ASIA: China India
ROW: All other regions

Source: Adapted using data from GTAP Data Package Version 4

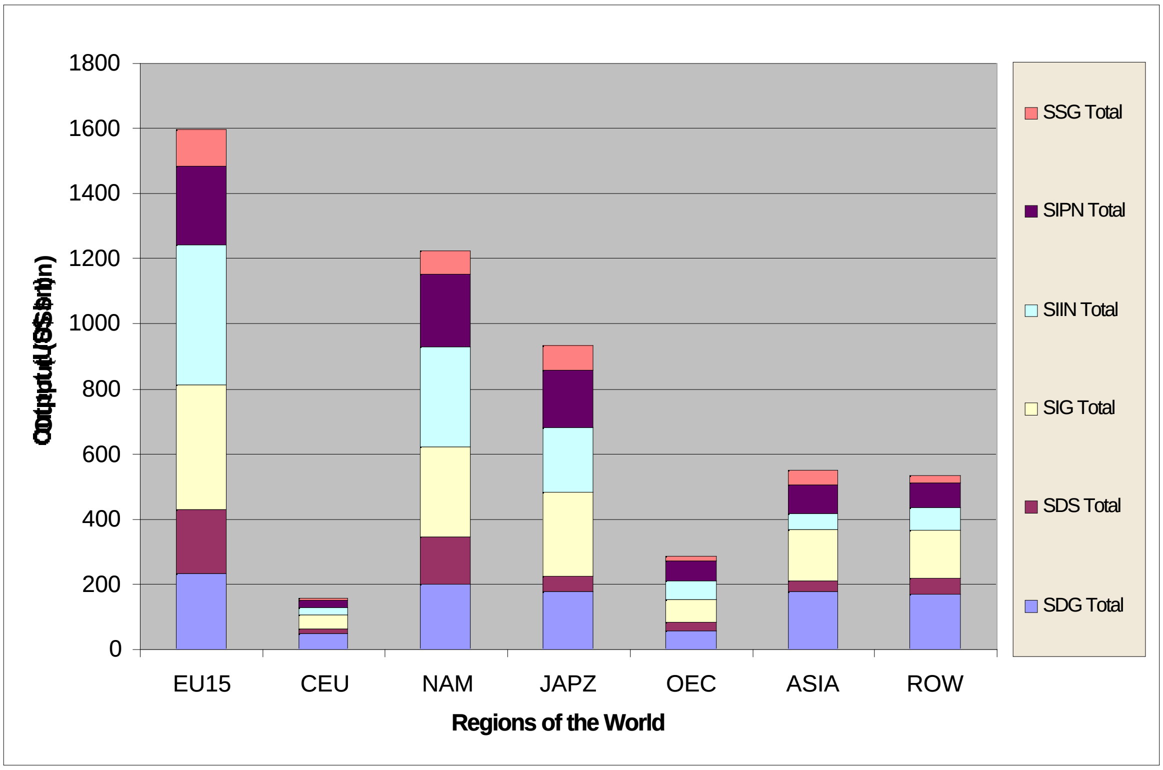
Table Three: Global Emissions Data by P/S&M Sector 1995 in billion tonnes of CO_2

P/S&M Sector	GTAP Sector	EU15	CEU	NAM	JAPZ	OEC	ASIA	ROW
SDG	01 Agriculture	0.07341	0.1028	0.02509	0.01548	0.03004	0.11323	0.13945
SDG	02 Coal	0.00513	0.01471	0.01128	0	0.00257	0.03295	0.00295
SDG	03 Oil	0.21614	0.32586	0.46171	0.02254	0.09096	0.18382	0.29046
SDG	04 Gas	0.14837	0.09503	0.42636	0.05748	0.02686	0.10543	0.10131
SDG	05 Electricity	0.44135	0.9648	0.93512	0.07542	0.09322	1.41	0.24758
SDG	13 Construction	0.07452	0.11025	0.15252	0.04615	0.02286	0.15937	0.11433
SDG	16 Textile Industry	0.01782	0.04484	0.01465	0.02081	0.00388	0.11542	0.02432
SDS	18 Non Market Services	0.1002	0.12045	0.09141	0.03491	0.0243	0.1153	0.14314
SIG	06 Ferrous and non ferrous metals	0.11502	0.21929	0.16558	0.17076	0.051	0.54258	0.15139
SIG	07 Chemical Products	0.08959	0.27509	0.18197	0.14295	0.02647	0.18762	0.10614
SIG	08 Other energy intensive	0.12652	0.17082	0.13605	0.06318	0.03936	0.45251	0.16087
SIG	09 Electronic Equipment	0.00418	0.02035	0.01465	0.02712	0.001	0.02033	0.00641
SIG	10 Transport equipment	0.03397	0.02904	0.03387	0.03059	0.00489	0.02386	0.01077
SIG	12 Other Manufacturing products	0.02149	0.03348	0.01785	0.01752	0.00488	0.07489	0.04446
SIG	14 Food Industry	0.04721	0.06393	0.03003	0.03055	0.01788	0.09974	0.09704
SIIN	17 Other Market Services	0.22228	0.12276	0.19087	0.08489	0.04082	0.14427	0.08094
SIPN	15 Trade and Transport	0.42505	0.3105	0.42796	0.09317	0.17516	0.58034	0.48529
SSG	11 Other Equipment Goods	0.05961	0.06231	0.0553	0.06834	0.01268	0.13959	0.04537

Key:
SDG: Supplier Dominated General EU15: European Union
SDS: Supplier Dominated Services CEU: Central Europe and
FSU
SIG: Scale Intensive General NAM: USA
SIIN: Scale Intensive Information Networks JAPZ: Japan
SIPN: Scale Intensive Production Services OEC: Other Europe Canada Australia and
New Zealand
SSG: Specialist Supplier General ASIA: China India
ROW: All other regions

Source: Adapted using data from GTAP Data Package Version 4

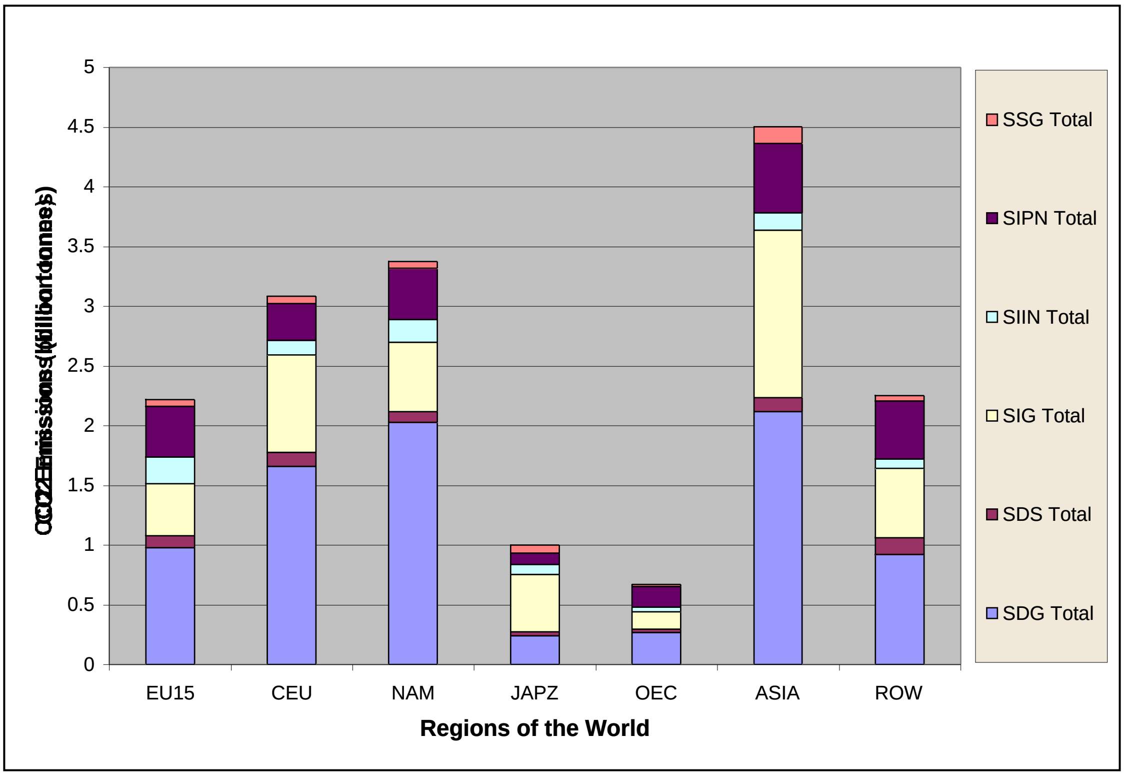
Graph One: Regional 1995 Output by P/S&M Sector (US$ billion)



Key:
SDG: Supplier Dominated General
SDS: Supplier Dominated Services
SIG: Scale Intensive General
SIIN: Scale Intensive Information Networks
SIPN: Scale Intensive Production Services
SSG: Specialist Supplier General
EU15: European Union
CEU: Central Europe and FSU
NAM: USA
JAPZ: Japan
OEC: Other Europe Canada Australia and New Zealand
ASIA: China India
ROW: All other regions

Note: Diagrammatic interpretation of Table 2: Adapted using data from GTAP Data Package Version 4

Graph Two: Regional 1995 Emissions by P/S&M Sector (CO_2 emissions billion tonnes)



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Diagrammatic interpretation of Table 3: Adapted using data from GTAP Data Package Version 4

Table Four: Effect of technological change in key pervasive technologies on P/S&M sector GHG emissions in developed and developing countries 2000-2050

P/S&M sector ***(Example industry)***	**Key technology***	**Net effect on developed countries GHG emissions****	**Net effect on developing countries GHG emissions****
Supplier Dominated General ***(Agriculture)***	B	No change	Increase
Supplier Dominated Services ***(Health and Education)***	BIN	Decrease	Large Increase
Scale Intensive General ***(Chemicals)***	B	No change/increase	Increase
Specialised Suppliers General ***(Instruments)***	IN	Increase	Large Increase
Scale Intensive Physical Networks ***(Wholesale and transport)***	IN	Increase	Increase
Scale Intensive Information Networks ***(Telecommunications)***	IN	Increase	Large Increase
Science Based General ***(Pharmaceuticals)***	B	Increase	Increase
Science Based Services ***(Business Services)***	IN	Large Increase	Large Increase

* Developments in information and materials manipulation are important in improving resource efficiency across all eight P/S&M sectors. Output increases were primarily driven by the 'key technology(ies)' shown.
** The net effect on GHG emissions reflects the trade off between increased resource efficiency (as a result of improvements in the manipulation of information and materials) and increased output (dependent on the 'key technology').

Key:
B = Biotechnology (Organism manipulation)
I = Information technology (Information manipulation)
N = Nanotechnology (Materials manipulation)