Resources and the New Economy: Heavy Constraints on a "Weightless World"?

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Abstract

Late 1990s claims of a shift towards a new economy in the US and other developed economies were said to accelerate earlier trends reducing the material content of production. The shift towards a postindustrial services economy is said to have been accentuated by application of new information and communications technologies dramatically reducing the material content of production. This offers the possibility for continuous economic expansion unconstrained by resources supply. This paper provides a critical analysis of these trends in relation to resource use by developed economies. It shows that trends towards a lower material content of production are occurring and this has led to poor demand conditions for primary producers. Nevertheless, these trends fall well short of eliminating Western economies dependence on key resources. This paper shows the changing role of resources in economic activity amongst developed economies.

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> "It is simply wrong to believe that nature sets physical limits to economic growth – that is, to prosperity and the production and consumption of goods and services on which it is based…. Although raw materials will always be necessary, knowledge becomes the essential factor in the production of goods and services." (Sagoff 1997: 83 & 90).

1. **A Little Context**

The relationship between natural resources and economic performance has periodically held center stage in political economy. The early Nineteenth Century Ricardo-Malthus doctrine of diminishing returns predicted that economic growth would ultimately grind to a halt: even if manufacturing exhibited increasing returns to scale and technical progress, diminishing returns to agriculture (as expanding farming moved onto successively less fertile land) would limit the growth of food supply and thus economic expansion leading to a long run steady state.[1] In 1865 Jevons made similar predictions for the exhaustion of coal supply as the key energy resource. Subsequent history demonstrated much greater potential for technical progress in agriculture and the discovery of new energy deposits and resources in oil enabled further expansion. In the early 1970s, however, an influential Club of Rome report prophesied limits to economic expansion from finite supplies of fossil fuels and key raw materials, as well as limits to the environmental capacity of the earth to absorb rising pollution (Meadows *et al.* 1972). The 1970s oil crises, heralding the end of the postwar Golden Age, appeared to some to confirm this vision. Subsequent analysis indicated that oil price rises were only one of a range of factors explaining the end of the postwar boom, but still a key one (e.g. Bruno and Sachs 1985; Glyn *et al*. 1990). The persistence of the effects was such that growth rates amongst developed countries did not return to their 1950-73 rates even when during the 1980s oil prices fell back to levels comparable (in real terms) to those before the 1970s price hikes.

Although economists have often been skeptical that resources are likely to constrain expansion over the longer term, in the late 1970s many others would have taken the ecologists' side over the economist Julian Simon's side in a famous bet over the future course of raw materials' prices – if economic growth were to lead to scarcities of finite natural resources one would expect to see sharp price rises. In the event Simon clearly won: over the 1980s in real terms the prices of primary commodities dropped to levels not seen since the Great Depression. In this some saw a vindication of the 1950s Prebisch-Singer hypothesis that in the long run relative prices of primary commodities would fall. In part this was attributed to dematerialization amongst developed economies associated with the shift from heavy to light manufactures and from manufactures to services. These trends were discussed in the 1980s, but shifts amongst key developed economies in the 1990s appear to have heightened them. Several economists – not to mention any number of "futurologists" – have characterized the impact of new information and communications technologies (ICTs) as creating a "weightless world" economy with limited or even minimal material content of production and very strong economies of scale and technical progress (Chichilnisky 1998; Coyle 1999; Quah 1997; 2001a; b). The result of this is that the standard limitations on economic expansion are relaxed, if not eliminated. In part this is expressed in terms of standard growth models with potentially a more rapid rate of technical progress and possible increasing returns to scale at the macroeconomic level. But this is also claimed to enhance the possibilities for reducing the material content of production and substitution of non-material inputs. A classic example here is software, which made Microsoft *the* company of the 1990s. The fixed costs of developing software may be high, but are largely human not material; once developed the material content and production costs of software are negligible.

With the end of the dotcom bubble, rising demand for and prices of resources and renewed concern over the stability of oil supplies the "weightless world" claims may now appear overoptimistic. Whereas in the 1990s many analysts were predicting sustained low oil prices, in the first decade of the 21st century predictions of sustained higher oil prices are commonplace. For all the emphasis on the new economy, US production of "light" autos rose by almost 50 per cent over the 1990s and was key to sustaining economic expansion after the collapse of the dotcom bubble (Rutledge 2005: ch. 9). The key question here is whether the new economy effectively decouples economic growth from natural resources as production becomes dematerialized and non-material inputs can be substituted for material ones. This paper proceeds as follows. Section 2 briefly surveys orthodox economic theory on natural resources and economic growth. Section 3 presents evidence on structural change and the new economy that might be expected to reduce demand for resources and selects economies for examination based on the contribution of ICT investment to their growth. Section 4 considers trends in energy use amongst these economies and section 5 considers trends in use of the main metals. Section 6 concludes.

2. The Economics of Finite Resources

Despite the Malthus-Ricardo results orthodox postwar growth theory, either of Solow or endogenous type, almost invariably abstracts from natural resource inputs. Until the 1980s most short-run macro adjustment models also assumed away resource inputs and any changes in their price. Various interconnected lines of defense are offered for this approach (Neumayer 2000; Nordhaus 1974; Solow 1974). Given futures markets and backstop technology the price profile of a scarce resource ensures substitution at exhaustion. Optimal depletion theory would lead one to expect a predictable rate of depletion rather than the sudden emergence of shortages. Of course this is subject to key "second-best" caveats – notably over whether the private and social discount rates coincide, imperfect property rights and the market structure of extractive industries – and it cannot simply be assumed that observed rates of depletion are in any sense optimal. As the price of the depleted resource rises one would expect to see standard economic responses: other, more abundant resource inputs will substituted for it and consumption of goods intensive in the scarce resource will be discouraged by rising prices. Rising prices will tend to increase incentives for more efficient use of the resource and recycling. It will also increase incentives to improve search and extraction technology and open up previously economically unviable deposits. Changes in technology and patterns of demand make previously essential resources obsolete whereas others assume center stage: the stone age didn't end from a shortage of stones; before the twentieth century there were few uses for oil.

Two mechanisms within orthodox growth theory in principle could act to sustain expansion even with finite resources. First, technical progress may be resource augmenting (possibly stimulated by rising resource prices) so that continuously higher output is possible for given resource inputs. Alternatively if it is possible to substitute reproducible capital for natural resources then indefinite expansion may be possible. Under Hartwick's rule if rents from exhaustible resources are invested in creating reproducible capital then an economy's total capital stock is maintained (Hartwick 1977); effectively "weak sustainability" is maintained as the rate of change of net wealth over time isn't negative. Indefinite growth of consumption is possible if the elasticity of substitution between reproducible capital and finite resources is unity and the reproducible capital share exceeds the resource share. Thus economic expansion could in principle be sustained with diminishing material inputs. Ironically, perhaps, the science of choice under ubiquitous scarcity denies that finite resources limit expansion. This approach has fed directly into green national accounting correcting GDP estimates for resource depletion (see section 5 below).

Several objections have been advanced to this line of argument by ecological economists, notably Daly (1977) who argues that the natural resources are complements, not substitutes, to other inputs (as well as seriously underestimating the resource demands of growing economies); and Georgescu-Roegen who argued that it neglects the role of entropy processes.[2] Daly rejects the substitutability argument, arguing that creating the "substitute" entails using more of the resource that it is supposed to be substituting for. Just as economists criticized the Club of Rome and others for naively extrapolating from past trends, even if technological progress has been resource augmenting and/or the elasticity conditions are currently satisfied there is no guarantee that we will continue to be the case in the future which is inherently uncertain, particularly as key resources are depleted (Neumayer 2000). As noted in section 4 below in relation to energy inputs, there are unresolved difficulties in estimating elasticities of substitution between energy inputs and reproducible capital.

Arguably these models are best viewed as "parables", rather than definitive claims that "the world can, in effect, get along without natural resources, so exhaustion is just an event not a catastrophe... at some finite cost, production can be freed of dependence on exhaustible resources altogether" (Solow 1974: 11). Although by definition there must be some physical limits to economic expansion, economists' grounds for believing that these would be unlikely to be binding in the foreseeable future are partly empirical. The absence of clear upward trends in resource prices - rather the reverse - and evidence that resources remain abundant relative to likely future demands are typically taken as grounds for believing resource constraints are unlikely to be binding.

Short run macro adjustment models, at least since Bruno and Sachs (1985), have often included the effects of raw materials and/or energy prices on output. Nevertheless, these effects are assumed not to affect the long run growth rate by imposing the assumption of unit elasticity between material inputs and capital, but sometimes evidence is produced to indicate that these effects do not persist. Thus even a sustained rise in the price of materials inputs is predicted to have a level effect on income but not affect its growth rate.

3. Structural Change and the “New Economy”

The main longer term trends amongst developed economies are too well known to need documenting in detail. The decline of agriculture followed by deindustrialization as production (and, more clearly, employment) shifts from manufacturing to services (and within manufacturing from heavy to lighter industries) have been analyzed extensively. These trends would be expected to lead a diminishing material content of output with development. In cross-section there is a hump-shaped relationship between the intensity of resource use and economic development (e.g. Rowthorn and Wells 1987: ch. 2). At low levels of development resource use tends to be low. Industrialization raises demand for resources but once deindustrialization sets in the resource content of production tends to decline with it, but not necessarily absolute resource use. Similar trends are observed with energy use in production (Snil 2003: ch. 2). This is the material input version the “environmental Kuznets curve” (EKC); similar trends have been claimed for greenhouse gases emissions and other pollutants both from these production trends and from increased demand for environmental goods at higher income levels.

Taken at face value, the “new economy” has elements of both continuity and radical novelty in relation to these trends. Authors differ in their use of the term, but a consensus interpretation would be that it entails significant productivity growth from enhanced use of new ICTs (Cohen *et al*. 2004; Temple 2002; Stiroh 2002b), but also that information has become increasingly important to economic processes. Information has unusual characteristics as an economic good: it has strong public good characteristics and is not intrinsically scarce (e.g. Hodgson 1999: Part 3; Quah 2001a). On the contrary, agents often face an abundance of information relative to their cognitive capacities. Although not necessarily disembodied from physical capital accumulation – indeed, depreciation of ICT capital equipment is relatively rapid due to high rates of technological obsolescence – the resource demands for ICT equipment are claimed to be relatively low and the driving force of growth is the development of new ideas. In growth theory terms this would be associated with raising the productivity growth rate and possibly increasing returns to scale at the aggregate level. All this is associated with higher productivity growth, lower inflation, falling unemployment and an apparent loosening on the constraints of expanding output (Jorgenson and Stiroh 2000).

Several developed economies saw heavy investment in ICTs in the 1990s and to a greater or lesser degree saw higher productivity growth. In part these trends would be expected to increase the shift towards services; although ICTs would be expected to enhance productivity in both manufacturing and services they are particularly important in providing potential productivity growth in services, typically assumed to have much less (but non-zero) potential for productivity growth than manufacturing, and in increasing the variety of services available and thereby enhancing the shift in demand patterns towards services. Quah (2001a) in particular argues that focusing exclusively on supply-side productivity effects of ICTs misses their key role in raising product innovation in the services sector and thus increasing demand. More generally, although investment in ICTs entails investment in physical assets, the key point here is that much of the increases in productivity comes from application of human capital, information and technology so that the expansion of the economy is driven by non-material factors. As one analyst of the US 1990s new economy boom concludes: “Investment in software is more important than investment in [computer] hardware” (Jorgenson 2002: 47).

Both the trends towards services in general and the new economy – and with it the implications for resource use – are subject to major caveats. Because the prices of services tend to rise more rapidly than manufactures due to their lower productivity growth much of the apparent rise in the services share is a price effect. Evidence on sector shares in constant price terms indicates the shares of manufacturing and services in output have remained fairly stable amongst the industrialized countries (Summers and Heston 1991; Rowthorn and Ramaswamay 1997). Moreover, many services are intrinsically tied to production of material goods and part of the apparent rise in services production may reflect the contracting out of services by manufacturers that were previously done in-house (Blades 1987). Following this, table 1 provides rough indicators for changes since 1990 in the shares of national value added (excluding government services) accounted for by goods, services whose production is directly linked to goods production and free-standing goods production. Amongst the developed economies although there has been some relative decline in goods production it is the share of services directly related to goods production that has risen with the share of free-standing services barely changing. This is consistent with other evidence that the growth in services connected to material production has been relatively rapid (Oulton 2001).

[TABLE 1 ABOUT HERE]

Thus whilst goods output only accounts for a minority of economic activity and employment in developed countries this cannot simply be take as evidence that their economies are becoming increasingly dematerialized. Other misconceptions about the services sector can be dispelled (Gallouj 2002). Conventional approaches typically underestimate innovation in the services while more detailed studies indicate significant innovation in this sector for developed economies over the 1990s, consistent with new economy arguments. In the US at least productivity grew strongly over the 1990s in those services that used ICTs intensively (Ark *et al*. 2003; Triplett and Bosworth 2003). Moreover, far from being universally low capital-intensity, services now account for around half of capital accumulation in developed economies (Gallouj 2002). This of course implies material input to services production. These trends have key potential implications the sustainability of growth processes with increasing demand for services: under Baumol's "cost disease" if equalization of wage growth rates (but not necessarily wage levels) is maintained between a technologically dynamic and stagnant sectors of the economy then relative costs of the latter will grow without limit and growth will decline as resources shift towards that sector. Oulton (2001) shows that the decline in the growth rate is dependent on the assumption that the stagnant sector only supplies final goods. If the "stagnant" sector supplies intermediate goods and experiences some productivity growth, albeit at a lower rate the dynamic sector, then a shift of resources to that sector won't lead to a decline in the growth rate. The reason for this apparently paradoxical result is that productivity grows in the dynamic sector both directly and indirectly through the contribution of productivity improvements in the inputs produced in the other sector. ICT investment in the services economy may therefore play a key role in sustaining economic expansion. Nevertheless, this is also consistent with goods production continuing to rise in absolute, if not relative, terms.

Arguably there are even stronger caveats with respect to the "new economy" than with the rise of the services economy. The collapse of the dotcom stock market bubble and the end of the 1990s US boom potentially helps the task of disentangling structural changes from purely cyclical factors. Much of the productivity gains experienced by the US economy in the 1990s were in the computer and allied industries with limited spillover effects on the rest of the economy (Gordon 2000; Stiroh 2002a); although the vast majority of studies of the new economy focus on the US, similar results were found for Finland (Daveri and Silva 2004). Whilst phenomenal growth in the computer industry did play a key role in the US 1990s expansion, other factors – notably favorable demand conditions and rising profits from sluggish or nonexistent wage growth and low real interest rates – were also crucial (Cornwall and Cornwall 2002; Thompson 2004). Gordon (2000) not only attributes much of the US 1990s growth to cyclical factors, but also queries whether the ICTs will lead to radical product innovations and increased demand on the scale of the major twentieth century innovations.

Beyond the US the impact of the new economy is even more ambiguous. As table 2 shows, the major economies varied in their levels of ICT investment with some approaching US shares. However, there was no clear relationship across countries between ICT investment levels and growth rates (Cohen *et al*. 2004; Colecchia and Schreyer 2002; Daveri 2002). Ark *et al*. (2003) found comparable levels of productivity growth in ICT industries themselves amongst the major EU economies, Australia and Canada as the US; however, the US saw significantly faster productivity growth in ICT-using industries. It may be that with investment lags and learning effects that these technologies will have a clearer impact in years to come. Amongst developed economies booms beyond the US, only six EU economies – Denmark, Finland, Greece, Ireland, Sweden and the UK – show clear evidence of the contribution of ICT investment to growth risen in the second half of the 1990s, to which can be added Australia and Canada.[3] Greece is excluded from the analysis here since ICT investments have grown rapidly but from very low levels. The largest continental European economies – France, Germany, Italy and Spain – saw stagnant or declining contributions of ICT investment to growth over this period. In the following analysis we focus upon these eight countries where the impact of new economy technologies appears to have been greatest.

[TABLE 2 ABOUT HERE]

3. Economic Expansion and Intensity of Resource Use

Standard analyses proceed by estimating an economy-wide intensity of use index (apparent consumption of the resource relative to GDP). Trends can then be divided into "weak" dematerialization, a fall in the intensity index, and "strong" dematerialization, an absolute decline in materials use with GDP growth. Although common in the literature, this form of analysis has been subject to several criticisms (Cleveland and Ruth 1999; Labson 1995). As an identity it may provide useful summary information, but does not explicitly identify economic relations driving these changes; in particular it does not directly account for the roles of relative prices, elasticities of substitution between inputs and technical progress. It also fails to take into account the derived nature of demand for resources – they are typically demanded as inputs to final goods. This may be crucial to assessing price effects: technical progress leading to greater efficiency effectively lowers the price of inputs to users and therefore could operate through a “rebound” effect to raise consumption – this was noted as far back as Jevons. Further, many studies fail to account adequately for the time series properties of the data; this is crucial to assessing whether there is a long-term trend towards greater efficiency or largely a one-off shift. In particular, recent studies have found that although both material use and GDP are clearly trended for developed economies and have unit roots, they are not cointegrated so that stochastic shocks tend to introduce permanent drift in the relationship between material use and GDP (de Bruyn 2000; Labson 1995); this would also hamper attempts to forecast future demand for resources. Earlier results indicating an EKC were based on inappropriate time series analysis (cf. de Bruyn 2000: ch. 6). Once re-estimated taking into account the degree of integration of the data series the expected relationship between pollution and income no longer holds and there is no presumption that growth, by raising income levels, will lead to lower harmful emissions. Finally, earlier analyses do not account for the extent to which increased trade specialization leads to developed countries importing resource-intensive products so that domestic resource consumption increasingly understates the resource content of final consumption in developing countries.

Whilst some studies have acknowledged these problems, data limitations hamper attempts to address them. Nevertheless, recently some national statistical authorities have begun to collect materials use statistics systematically. Unfortunately many of these are only available for recent “snap-shots” and so this limits meaningful time-series analysis. For the US, 20th century figures up to 1995 indicate rising total consumption of non-renewable materials until the 1960s but roughly constant since then, thus implying declining intensity of use (Matos and Wagner 1998). This study does not estimate the material content of imports into the US, although it does note more rapid increases in material consumption in the rest of the world. The aggregate picture for the EU over 1980-2000 was roughly unchanged for total materials consumption, implying a trend decline in intensity in use. Eurostat (2002) found broadly similar trends for the US and Japan, although with the US intensity in use was around 30 per cent higher than the EU and fell at a slower rate over this period. Within these EU-wide trends there was considerable variance between countries, with “strong” dematerialization only clearly observed in France, Germany, the Netherlands, Sweden and the UK. There was no clear association between ICT-based growth amongst EU countries and dematerialization. Moreover, although there is evidence of an EKC relationship in terms of material consumption for Denmark, the Netherlands and the UK such a relationship was not found for the initially poorer EU members with their material consumption per capita continuing to rise with income. This suggests that for material consumption at least if an EKC relationship does exist then the turning point is at a relatively high income level, although the high level of dispersion across countries precludes clear conclusions. Other studies of developed economies point to weak dematerialization trends, but continued absolute growth of material use and considerable levels of waste (WRI 2000).

Of particular relevance here is the material content embodied in ICT equipment. As noted above, rapid technological obsolescence leads to relatively rapid depreciation and replacement of ICT equipment. Although the new economy view has tended to assume that this equipment has relatively low material content compared to capital equipment in more traditional industries. Information is limited, but piecing together available data Williams *et al.* (2002) found that the total material use in semiconductor manufacturing was over 600 times the mass of the final product, a figure orders of magnitude larger than for traditional manufactures. The complexity of the final product and the levels of refinement and purification of material inputs required leads to high material requirements relative to the final product. Moreover, these products typically require (albeit small) inputs of relatively scarce specialist materials. This suggests more generally that whilst the final output of new economy industries may have relatively low material content, the impact of increasingly complex products and organization of production on secondary material inputs cannot simply be read off from this. Analysis at this level of aggregation can only provide broad indicators and we now move to analyzing more specific materials.

4. Energy Demand and Economic Expansion

The rise of modern economies was built upon the shift from biomass to fossil fuels as chief energy providers (Snil 2003: ch. 1; Roberts 2004: ch. 1). Whilst generally cheap fuel masked the importance of energy for much of the 19th and 20th centuries' economic expansion, since the 1970s oil crises the economic and strategic significance of energy hardly needs to be stressed.

Over the 20th century as a whole energy consumption rose at roughly the same rate as GDP, so that energy intensity of real income was similar at the end of the century as the start; but this picture conceals rises in the intensity up to 1973 and falls thereafter (Hannesson 2002; Snil 2003: 65-9). In the aftermath of the 1970s oil price rises the energy intensity of GDP was reduced in the developed economies as higher oil prices led to energy conservation. Structural changes in these economies might also be expected to continue this trend the evidence is less clear from the 1980s when oil prices fell back in real terms. Nevertheless, improvements in energy efficiency tend to induce "rebound" effects: consumers heat their homes warmer in the winter, use more air conditioning in the summer and drive larger cars; thus, post-1973 trends toward more fuel efficient autos in the US were reversed in the 1990s with falling real fuel prices and the rise of SUVs (Roberts 2004: chs 6 & 9; Rutledge 2005: ch. 9).

In the 1990s there was widespread optimism that for the developed countries "additional energy use is likely to be minimal, and there appears to be a consensus that little or no growth in overall demand is likely…. Most of the countries that record high per capita use of energy have reached the point at which energy demands are unrelated to the level of economic growth" (Churchill 1993: 442-3). We pursue this issue further here for our ICT-intensive growth countries. Table 3 shows the evolution of the ratio of total primary energy supply and in relation to real GDP (calculated on a PPP basis) for these countries. Trends are clear: although the energy required to produce a unit of GDP has continued to decline energy consumption has largely continued to rise with GDP growth, although with Denmark, Sweden and the UK there is some evidence of stabilization. Economic expansion has not therefore become decoupled from energy use. There remains considerable dispersion in the energy-GDP intensities so that although both Canada and the US in particular have seen improvements in energy efficiency they remain relatively high energy intensity economies in comparison with other developed countries.

[TABLE 3 ABOUT HERE]

The question remains, though, whether the 1990s experience is anything more than a continuation of earlier trends towards lower energy intensity of GDP. Further testing for a structural break in 1990 is reported in table 4. For all sample countries except Denmark this indicates a break in this series (although the Australian and Finnish cases are marginal). For four of the countries, the rate of growth of energy efficiency increased in the 1990s, consistent with a new economy thesis. Ireland is a particularly striking case of combining rapid economic growth with gains in energy efficiency, although this wasn't sufficient to prevent rises in Irish total energy consumption. For Finland, the US and UK, though, the rate of growth of energy efficiency declined in the 1990s relative to earlier in the post-1973 period. Whilst the Finnish case may be affected by its severe recession in the 1990s, but the key UK and US cases indicate that new economy trends do not necessarily lead to faster declines in energy intensities. Only limited reliance can be put on these results with limited observations, but they do indicate trending in the data rather than simply a structural break around 1973.

[TABLE 4 ABOUT HERE]

It was noted above that past studies have been criticized for being atheoretic and/or not adequately accounting for the time series properties of the data. Advances in time series analysis means we cannot simply view an observed time trend as evidence of a deterministic trend. In particular, if energy consumption and GDP are not cointegrated, although both trended, there may be no clear trend in energy intensities. In an earlier study de Bruyn (2000) found evidence of this for energy (and steel) use amongst four developed economies. An intuitive explanation for this is that shocks to material consumption are to GDP may be largely unrelated. Thus, a material saving innovation could lead to a reduction in the material intensity of production, but subsequently material intensity rises again for "rebound" effect reasons; technological innovations may raise income levels or even growth rates without having an impact on energy intensities. Nevertheless, it is not possible to pursue detailed time series econometric analysis meaningfully with limited observations, particularly with evidence of a structural break around 1973. Instead, following Ormerod (1994: ch. 7) and de Bruyn (2000: ch. 8), we can use the concept of "attractor points". By plotting annual observations for (logged) energy intensity relative to the previous year's value it is possible to discern several points: it provides an analysis of whether intensities show clear trends or are largely cyclical; if they are cyclical it can indicate the attractor point around which intensities fluctuate and the magnitude of these cycles. Moreover, it can indicate whether there are periodic shifts before cycles settle down around a new attractor point. This approach is particularly useful here where there are pronounced cyclical variations and we are interested in determining whether there is a trend fall in resource intensity or periodic shifts in response to regime changes; in other words, distinguishing between cases of continuous technological change from shifts associated with a particular cluster of innovations (cf. de Bruyn, 2000: ch. 8). Thus it can help illuminate whether there has been a clear shift towards lower intensities of resource use with new economy trends.

The results in figure 1 display a diversity of experience, to some extent in contrast with the smaller sample in de Bruyn (2000: ch. 8). For Australia, Canada, Denmark and Sweden energy-GDP ratios are consistent with attractor point patterns for much of the post-1973 period but some evidence of trends towards lower intensity in the most recent years. However, as this only applies for a small number of recent observations it cannot be presumed to indicate a continuous trend and may resume attractor point behavior in the future. The Finnish case indicates attractor point behavior for energy intensity throughout the post-1973 period, although this may partly reflect the movements in GDP with its 1990s recession. Amongst Ireland, the UK and US, though, there is clearer evidence of trend decline in intensity over this period; thus, although econometric estimates above pointed to a slowing down in the rate of decline of energy intensity for the UK and US this analysis points to greater evidence of a continuous decline in energy intensity than for other sample countries.

[FIGURE 1 ABOUT HERE]

We can investigate this further by decomposing changes in energy intensity into the effects of technological change and structural change in the economy (Howarth *et al*. 1991; de Bruyn 2000: ch. 9). This utilizes Laspeyres indices of change due to intensities holding sectoral shares constant and of change due to structural change holding intensities constant; necessarily over discrete intervals this will produce a residual but, as Howarth *et al*. (1991) point out, this can be interpreted as an interaction term. Whilst in principle ICT use could have a positive impact on energy intensity via both channels, the expected direct impact of ICT use in reducing energy consumption is limited; rather the implication of the hypotheses discussed above is that the main impact of ICT use would be in promoting the expansion of sectors with low energy use. Unfortunately for most of our sample countries suitably disaggregated data are not available; nevertheless, typically the transportation and residential sectors are the largest single consumers of energy and are unlikely to be significantly affected by ICT use. Table 5 reports the contribution of increased energy consumption by these sectors to total rise in energy consumption over 1990-2000; for the Anglo-Saxon countries these sectors continue to account for the majority of increased energy consumption to the extent that in the Canadian case the transportation accounts for more than the rise in all energy consumption, implying strong dematerialization in other production sectors. Patterns amongst the Scandinavian economies are more varied, but transportation is a major contributor in all cases except Finland, with the variation being largely down to differences in residential energy consumption. In this sense arguments that continued output growth has become decoupled from growth in energy demand are borne out, at least for the Anglo-Saxon countries; growth in production of goods and services makes a relatively small contribution to the growth in energy demand.

[TABLE 5 ABOUT HERE]

Detailed sectoral evidence on energy consumption is available over this period for US manufacturing output, Canadian non-agricultural production and UK output in respect of consumption of energy from fossil fuels. Table 6 reports decomposition results for this data. For Canada and the UK the results clearly indicate that the effects of structural change are outweighed by the effects of falling intensities within sectors. The US results are harder interpret; the overall effects are distorted by the petroleum refining and coal sector, by an order of magnitude the most energy intensive sector. Excluding this sector reverses the relative importance of sectoral change and changing intensities. Isolating the combined effects of those sectors that either produce ICT goods or use them intensively (following the classification of Ark *et al*. 2003) indicates that this only accounts for a minority of the decline in energy intensities,[4] which appears largely to be due to structural shifts and technological progress unrelated to new economy trends. Note that this is the whole contribution of these sectors to changes in energy intensities: not all of the industries within these categories will be ICT-intensive and not all of their relative expansion or change in energy intensities can be attributed to ICTs. The relatively high Canadian figure partly reflects the inclusion a catch-all ‘offices’ sector in the ICT-using group. Thus, these decompositions are likely to overestimate the contribution of ICTs to reducing aggregate energy intensities.

[TABLE 6 ABOUT HERE]

Thus although the energy *intensity* of GDP has fallen in developed economies, total use of energy continues to rise. With rising absolute levels of energy use, even if new technologies offer the potential for continuous productivity growth this won’t necessarily lead to economic expansion freed from material constraints.

As noted above, orthodox accounts have typically imposed the assumption that changes in material supplies and their prices do not affect the growth rate because of substitution effects. Here this turns on whether capital and energy are substitutes – and, if so, at what elasticity – or complements in production. Standard analysis since Bruno and Sachs (1985) views energy as an input to the production process with limited substitution possibilities, at least in the short run.[5] In the short run therefore oil price rises have a significant negative impact on output and employment. The predicted absence of a longer term impact on growth is dependent on substitutability of capital for energy. However, econometric studies have produced a wide range of estimates, some finding that capital and energy are complements (Frondel and Schmidt 2002; Neumayer 2000: 322-3), although recent studies find that over the medium term capital and energy are substitutes at approximately unit elasticity, consistent with standard analysis (e.g. Thompson and Taylor 1995). Thus, energy price levels would not affect the long run growth rate. Nevertheless, only limited reliance can be placed on this: “Overall, it has to be said that a satisfactory explanation for the variation in econometric studies has not been found yet and that we do not have a reliable answer on the question whether energy and manmade capital are substitutes or complements” (Neumayer 2000: 323-4). In particular, there are well known conceptual problems with estimating aggregate production functions using cost data and Frondel and Schmidt (2002) find that these results can be explained as an artifact of using cost data: with the standard static translog approach the larger the cost shares of capital and energy the more likely the estimated cross-price elasticity is to be positive and thus indicate that the two are complements. Reported elasticity estimates in the literature vary in accordance with capital and energy cost shares as predicted.

Whatever view is taken of the long term effects of energy prices in the short term higher energy prices, particularly oil prices, significantly affect economic activity. Carruth *et al.* (1998) found that the real price of oil was strongly significant in explaining the US unemployment rate throughout the postwar period with better predictive powers than standard macroeconomic forecasts, even after accounting for the effects of any anti-inflationary policy response. Murchison and Siklos (1999) found that the price of oil and unemployment were cointegrated for developed economies. Some studies indicate that the effect of oil price changes is asymmetric, with price rises having a significantly larger effect on output than falls (Hamilton 2003). Recent simulations indicate that a substantial rise in energy prices would have a smaller negative impact than in earlier decades, in line with falling energy intensities, but would still be significant (Hunt *et al*. 2002; IMF 2005: ch. 4; OECD 2004: ch. 4). However, unlike earlier analyses these simulations focus on the impact on inflation (and sometimes terms of trade effects), with limited modeling the effects of energy prices on production. It thus remains unclear what the effects on output of sustained higher oil prices would be.

Forecasting energy supply and demand is notorious for providing either inaccurate forecasts or ones whose accuracy derives more from errors canceling than accurate estimation of the underlying mechanisms (Snil 2003: ch. 3). The price of oil is scarcely determined in free market conditions, with partial cartelization of producer countries through OPEC, concentration amongst oil companies and domination of demand by large consumer countries. Amongst producer countries there is wide variation in extraction costs, with Middle East producers having by some distance the lowest cost with extraction costs. The price of oil thus does not simply reflect its scarcity or extraction cost, but is the result of a complex interaction between partially cartelized producer countries, oligopolistic companies and major purchaser countries. Real oil prices declined over the first half of the 1980s and remained low by post-1973 standards from 1986 (excepting the first Gulf war) until by 1998 they had fallen to levels comparable (in real terms) to pre-1973 prices; since then oil prices have sharply risen in real and nominal terms from 1999 (IMF 2005: ch. 4; OECD 2004: ch. 4; Rutledge 2003). Real prices remain below 1979/80 peaks, which would be around $80 a barrel in current prices (IMF, 2005: ch. 4). Whereas analysts in the late 1990s could be found predicted continued low oil prices – even the 2005 US Energy Department report was expecting prices in the $27-35 a barrel range (EIA 2005: 3) – one can now readily find prophesies of oil prices rising to $100 a barrel and persisting at such levels. Recent rises reflect not emerging scarcity, but in part attempts by OPEC to raise prices by restricting supply, limited investment in new extraction and continued disruption to Iraqi supplies against growing global demand from expansion in China, the US and elsewhere (e.g. IMF 2005: ch. 4; Stevens 2005). Analyses of oil price developments point to at least some convergence of interests and tacit cooperation between the US (as the world’s largest oil consumer and second largest producer) and OPEC to maintain prices above some putative free market level (Goldstein *et al*. 1997; Rutledge 2003). Whilst OPEC clearly wishes to maintain high prices, above a certain level these would to trigger a global economic downturn in the short run and greater conservation measures and development of alternative energy sources over the longer term. For the US, particularly after the fall of oil prices in the late 1990s, lower prices reduce the profitability of, and hence capacity investment in, oil production outside the Middle East (including in the US itself). It is thus not just defense of domestic oil producers, but a more general security concern that lower prices would discourage development in the relatively costly Central Asian, Latin

American and West African oil fields and thus undermine US efforts to diversify its supply away from Middle Eastern sources.

Despite earlier forecasts of flattening US energy demand, it accounted for a fifth of the increase in global oil demand over 1995-2004 (OECD 2004: 129). Whilst higher energy prices would be expected to have some effect on restraining demand growth, rebound effects tend to undermine gains from greater efficiency. The US Department of Energy forecasts continued energy demand growth, with oil demand predicted to rise by 37 per cent to 2020 and demand for transportation fuels to rise by 40 per cent over the same period so that by then transportation alone is predicted to account for the same level of petroleum demand as total US demand in 1999 (Rutledge 2005: ch. 9). In the US particularly continued growth in oil demand is likely because of transportation, reflecting not only consumer decisions but also path dependency effects of 20th century urban planning and energy policy decisions to construct urban and suburban America around private car use and downgrade public transportion (Rutledge 2005: chs 2 & 9; Roberts 2004).

Despite the dominance of the developed countries in energy demand – by 2000 the US alone accounted for over a quarter of global primary energy demand and the G7 countries 45 per cent, whereas the poorest quarter of the world's population only account for 2.5 per cent (Snil 2003: 50) – the industrialization of major developing economies is projected to account for much of the future rise in energy demand. China alone accounted for a quarter of the rise in global oil demand over 1995-2004 (OECD 2004: 129). Nevertheless over the 1980s the energy intensity of China's GDP fell by 40 per cent and energy efficiency continued to rise at similar rates during the 1990s (Snil 2003: 139; Fisher-Vanden *et al.* 2004). Rising relative energy prices and greater economic efficiency helped achieve this, but its sustainability is less clear as China's industrial structure develops and demand for private autos continues to grow rapidly. In general there is considerable uncertainty over the growth of energy demand in developing economies. Over the past twenty years total commercial energy intensity of GDP has fallen amongst the lowest income countries but has grown slightly amongst middle-income countries.[6] Optimistic scenarios expect increasing energy efficiency with industrialization amongst these countries, but as already noted the presumed EKC relationship is not robust and these scenarios are critically dependent upon these countries having access to relevant technology and pursuing appropriate energy policy and pricing choices (cf. Churchill 1993).

On the supply side, in the medium term attention has focused on potential disruption to Middle Eastern oil supplies in particular (e.g. Rutledge 2005: chs 10-11). One result of rising US oil demand has been to increase its dependence on imported oil, leading to concerted efforts to diversify its supplies away from Middle Eastern producers given obvious security concerns there. Attention has shifted to what has been dubbed "the new great game", with strategic rivalry over the oil fields of former Soviet central Asian republics (Kleveman 2003; Rutledge 2005: ch. 8). Key players here are the US, China through its growing energy demand and Iran as a major regional oil producer; China in particular has been actively pursuing agreements with key producer countries to secure supplies and has been willing to pay a premium price to ensure this. Although the Caspian Sea region reserves may be large, they are landlocked; since the mid-1990s the US has been committed to a 1000 mile pipeline project linking oil fields in Azerbaijan, and potentially Kazakhstan, through the Southern Caucasus to refineries in Turkey in an effort to secure oil supplies. Nevertheless, early projections that Caspian region oil had the potential to rival major

Middle Eastern producers now appear overoptimistic with estimated reserves now comparable to smaller OPEC producers (Roberts 2004: ch. 2; Rutledge 2005: ch. 8); moreover, Central Asian oil production costs are 3-4 times those of Middle Eastern producers. For all the strategic significance attached by US administrations since the mid-1990s to Central Asian oil, it is unlikely to be able to provide a major alternative source of supply.

Relatively high levels of medium term investment levels would be required to meet projected increased demand (Birol 2005). Conventional forecasts, though, assume that ample global reserves of oil remain (EIA 2005; OECD 2004: ch. 4). As with coal before, a century of analysts have prophesied the end of oil supplies only to be confounded: new reserves are discovered, search and extraction technologies improve, fuel efficiency rises and alternative energy sources are being developed and falling in price (e.g. Snil 2003: ch. 4).

Matters may not be so simple over coming decades. Despite the slightly conspiratorial air of some of their writings, there are grounds for taking contemporary oil pessimists seriously. The key issue is not the end of oil supplies as such, but of consumption exceeding production levels as rising demand hits oil production passing its supply peak with concomitant effects on prices. In the “Hubbert’s peak” interpretation supplies of oil follow a bell-shaped distribution over time. For these analysts estimates of initial global oil reserves have been relatively steady since the 1970s indicating around 1.1 trillion barrels remain (of an estimated 2 trillion originally), about 40 years’ consumption at current rates (Aleklett and Campbell 2003; Holmes and Jones 2003; Heinberg 2003: ch. 3; Roberts 2004: ch. 2).[7] New oil discoveries peaked in the 1960s and have been in decline since; there have been no major new oil field discoveries since the 1970s; oil extracted per foot drilled has also declined. Alternative energy sources are being developed, but their supply remain limited and their substitutability for oil is limited for key uses, particularly transportion (Heinberg 2003: ch. 4; Roberts 2004: ch. 8; Snil 2003: ch 5).[8] World oil production is predicted to peak within the next 30 years on these projections, as early as the next 5-15 years on the most pessimistic end of the scale.

Critics charge that this confuses known with potential reserves and that production: reserves ratios have been fairly steady for decades (Lynch 2002; 2003: Snil 2003: ch. 4). The question is less whether oil supplies can be analyzed as following a “Hubbert’s peak” than in interpretation of relevant data. Essentially critics accuse the pessimists of using very limited data to place a geological interpretation on an economic phenomenon: the rate of extraction, and exploration for new reserves, depends on price incentives so that lower rates of output and/or of discovery of new reserves cannot simply be taken as indicating depletion. New technologies of discovery and extraction emerge and their development is likely to be stimulated by higher prices. Since the 1980s several major OPEC countries have significantly revised upwards their estimated reserves. The US Geological Service (USGS) estimates that proven oil reserves stand at around 1.7 trillion barrels (most of which is in the Middle East) with an estimated further 900 billion barrels lying undiscovered, although with continued growth in world oil consumption this would lead to hitting peak production around 2040 (Holmes and Jones 2003; Roberts 2004: ch. 2). However, the USGS regards these estimates for undiscovered oil as at the lower end of their predictions, with the likely level of undiscovered oil to be another 1-1.5 trillion barrels.

Nevertheless, there are grounds for skepticism about these (revised) estimates. Enough is known about the geographical distribution of oil reserves to be reasonably sure that the “easy” oil discoveries are likely to be over. Whilst OPEC countries had probably underestimated their reserves before the 1980s, subsequent revaluations appear to have gone beyond levels that might be justified by new discoveries or improved technologies and reflect instead OPEC policy of relating country sales quotas to estimated reserves levels (Roberts 2004: ch. 2); in 2005 the International Energy Agency, the IMF and the G7 have all pressured OPEC to open their oil field estimates to independent audit. Thus in 1985, Kuwait announced that it possessed 50 per cent more oil than it had previously declared and other OPEC states followed suit. In 2005 Kuwait still claims the same reserve levels as in 1985.[9] Matthew Simmons, an energy investor who advises the Bush administration, has recently produced detailed evidence indicating significant overestimation of Saudi oil reserves which may soon pass their peak (Simmons 2005). More evidence of the questionable nature of estimated reserves was provided in 2004 when Shell reclassified a fifth of its “proven” reserves as “unproven” (Roberts 2004: ch. 7). The official US estimates largely rely on estimates from producer countries and curiously described their upward revision in the late 1990s in these terms: “these adjustments to the USGS and MMS [Minerals Management Service] estimates are based on non-technical considerations that support domestic supply growth to the levels necessary to meet projected demand levels”. (EIA 1998: 217). Moreover, the dynamics of peak production would be likely to increase consuming nations’ reliance on Middle Eastern oil supplies as peak production is likely to occur earlier amongst other producer countries. The US Department of Energy was sufficiently concerned to commission a report in February 2005 on the “Peaking of World Oil Production: Impacts, Mitigation, & Risk Management”, although it has not officially been made publicly available.[10] The report concludes that “the bottom line is that no one knows with certainty when world oil production will reach a peak, but geologists have no doubt that it will happen”, and that this has the potential for unprecedented disruption to developed economies. A non-geologist cannot be expected to adjudicate on these disputes and the safest conclusion is surely that oil reserves remain fundamentally uncertain and that we lack the information necessary to estimate them reliably; but there are grounds for expecting limits to the rate of expansion of supply relative to demand over the short term and potentially beyond.

Rising demand for oil relative to limited supplies has led some analysts, notably Klare (2002), to predict intensifying geopolitical conflict over these resources. It hardly needs pointing out that oil is the key strategic resource and much of it is based in unstable countries with ongoing conflict in the Middle East and strategic rivalries over Central Asian oil fields. Nevertheless, there are a range of possible strategic responses, as indicated by the differences between the US and European countries policies toward Iran and Iraq (amongst other countries). These analysts tend to assume that dependence on oil determines foreign policy, particularly in the US, whereas it may be more useful to examine how the underlying strategic assumptions of countries’ foreign policies determine their policy toward oil producers (cf. Bromley 2005). Intensifying conflict over oil is clearly a distinct possibility, but it is not inevitable.

The optimists may well yet trump the pessimists with new oil discoveries, but even some relatively optimistic predictions predict a peak in oil extraction within decades against continued growth in demand. Despite dismissing pessimistic forecasts one analyst concludes: “Whatever the future gains may be, the historical evidence is clear: higher efficiency of energy conversions leads eventually to higher, rather than lower, energy use, and eventually we will have to accept some limits on the global consumption of fuels and electricity” (Snil 2003: 317). We now turn to the issue of metals.

4. Economic Expansion and Demand for Metals

Deciding which metals to focus on requires some judgment. In 1946, the US Congress passed the Strategic and Critical Materials Stockpiling Act and the US government maintains stocks of strategic materials for which the US has high import dependence and overseas sources of supply face potential disruption. With the end of the cold war some of these threats have receded and many of the metals are only used in small quantities but in strategic military industries. Some key metals are used in small quantities but with limited substitution possibilities in ICT equipment production, but the focus here is on the most heavily used metals, in descending order: steel, aluminum, copper, zinc, lead and tin.

The difficulties encountered when attempting to model energy demand are, if anything, greater still with metals. Again demand is derived rather than directly for the product: growth in demand for metals can be decomposed into output growth, the material intensity of production of each commodity and the changing product composition of output. However, sectoral data on use of metals is not generally available. Earlier studies found clear evidence of a structural break around 1973 in demand for the major metals, with demand for these metals falling significantly below their postwar trend growth rates (Cleveland and Ruth 1999; Roberts 1996; Tilton 1990: appendix). In part this reflects the slowdown in GDP growth rates, but it also marks a switch in the nature of growth amongst the developed economies from rising intensity of metal use in production to falling intensity (both from shifts in product mix and through resource-saving technology in particularly industries). Both declining intensity of use and falling growth rates therefore contributed to lower growth or stagnation in demand for metals. Examining earlier versions of the argument that structural changes in the developed economies had decoupled economic growth from metals demand Tilton (1989) concluded that this was premature and that declines in the metal intensity of output still left demand for metals dependent on economic growth and argued that industrialization elsewhere in the world might act to increase demand for metals. Capital equipment, construction and consumer durables production all tend to use metals intensively, although high technology production and its associated capital equipment are relatively light in metals use. Recently the industrialization of China and other major developing economies has sharply increased demand for metals. Although economic development may lead to a declining material content of production over time, in the short run expansions often raise demand for raw materials as capital goods and construction tend to intensive in these. Thus in the short run income elasticities of demand for metals may be relatively high (Tilton 1989).

However, it is unclear whether the material intensity of production declined continuously over the postwar period or whether there was a one-off shift in the intensity of metals use. Labson (1995) found that there was a clear structural break around 1973 in metals intensity by the major economies; however, he found that there was no clear trend in the intensity of metals use once this break was allowed for. Long series of data are only available for the world and US, but this does allow extension of post-1973 data points. Figures 2 and 3 show (logged) intensities of metal use relative to industrial production indices for the world and the US.

[FIGURES 2 & 3 ABOUT HERE]

At the global level there are downward trends for lead, tin and zinc, although this may be due more to substitution of other metals than a general dematerialization trend (Tilton 1990). Steel intensity also displays some decline since the 1970s although this has risen again recently. Aluminum intensity has risen over the post-war period, whilst copper intensity fell to low levels in the 1970s and 1980s but has since recovered. Data for countries besides the US is only available for a limited time period and ratios may be misleading with relatively small metal consumption figures. Therefore further analysis is confined to the US, although available figures do not indicate any clear trends in metals intensities over the 1990s for the other new economy countries.

For the US, as shown in figure 3, there are similar trends for all six metals: sharp falls in intensities over the 1970s and early 1980s and little clear trend thereafter. Not surprisingly from visual inspection of metals intensity trends there is varied evidence of cointegration between metals consumption, industrial production and relative prices either for the world or the US. For four of the metals a Johansen test indicated a cointegrating relationship for world demand; table 7 reports estimates of an error correction equation of the following form:

$$m_t = \beta_1 \Delta q_t - \beta_2 \Delta p_t + \beta_3 (m_{t-1} - \alpha_0 - \alpha_1 q_{t-1} - \alpha_2 p_{t-1} - \alpha_3 t) + \mu_t \qquad (1)$$

where m is demand for the metal, q is the index of industrial output, p is the price of the metal prices relative to the producer price index, t is a time trend designed to capture technical progress (broadly defined to include the effects of structural change) and μ is a random error term (all variables except t are in logs). Structural stability tests were performed to test for breaks in 1973, 1980 (consistent with metals price data discussed below) and 1990 (to test the new economy thesis).

[TABLE 7 ABOUT HERE]

For these metals, predictably the long run results are largely driven by the close correlation between industrial production and metal demand, but for lead and steel there is also a significant – if small – trend decline in demand consistent with resource-saving technical progress. For aluminum there is no evidence of a structural break in 1990 but strong evidence of earlier ones. For both lead and steel there is evidence of a significant structural break around 1990, although with lead this does appear to be consistent with a new economy thesis with actual values largely below fitted ones over the 1990s this is less clear with steel. There is no evidence of a structural break for zinc.

For those metals where the Johansen test did not indicate a cointegrating relationship, but in the light of results indicating that industrial production and (less clearly) metals demand, was I(1), the following difference relationship was estimated:

$$\Delta m_t = \gamma_0 + \gamma_1 \Delta q_t - \gamma_2 m_{t-1} + \gamma_3 q_{t-1} - \gamma_4 p_{t-1} + \mu_t \qquad (2)$$

The results are reported in table 8. For the two metals estimated using (2) the fit is generally poor; although the estimates imply a long run income elasticity of demand above unity for copper, it is not significantly above unity on a Wald test; the results for tin indicate a long run income elasticity of demand significantly below unity. Although Chow tests indicate a structural break in 1990 for both metals, it is not clear that this indicates systematically lower than predicted demand over the 1990s and in both cases there is also evidence of significant structural breaks earlier. In general little reliance can be put on results for these two metals given the low power of the estimation.

Estimating (1) for US data where a Johansen test indicates a cointegrating relationship and (2) where it does not gave the results reported in tables 9 and 10. Not surprisingly from visual inspection of the plots in figure 3 for most metals testing did not indicate a cointegrating relationship. The fit for aluminum and steel is generally good, with significant negative price coefficients as well as significant positive income elasticity estimates. For aluminum the trend is segmented for 1950-73 and 1974-2002, indicating that technological change was resource-saving over the latter period.[11] For steel there is evidence of resource-saving trends throughout the post-war period, but only weak evidence of a structural break after 1990 (and roughly as strong evidence for a structural break in 1980).

For the other four metals, estimates of US demand produced mixed results. Only for zinc was the price coefficient negative and significant. Except for tin the lagged industrial output coefficient was positive and significant; in all cases the implied long run income elasticity of demand was below unity (significantly so on Wald tests in each case). There is some evidence, except for tin, of earlier structural breaks but no clear evidence for the new economy thesis. Overall the picture for these four metals is one of sluggish post-war demand growth in the US, a trend which the new economy has not significantly accelerated. (For estimates of (2) including a trend term was not significant for either world or US demand).

Demand trends can also be examined in terms of price movements. Ocampo and Parra (2003) model the behavior of primary commodity prices (both mineral and agricultural) since 1900. In general the relative decline of primary commodity prices over the 20th century can be accounted for a step fall around the time of the Great Depression with no trend thereafter and another structural break around 1980 followed by a negative price trend. These findings hold for metals in general too; modeling specific metals prices produces more variable results but the general picture is of falling metals prices since 1980. This is consistent with the new economy thesis to the extent that it is consistent with dematerialization trends amongst developed countries, although it predated the ICT investment boom. Nevertheless, short-term volatility tends to predominate any long-term trends in commodities prices. As table 10 indicates, in the first half of this decade the composite metals price index has risen sharply relative to post-1980 values. Part of this reflects cyclical up-turns in demand relative to inelastic short run supply; it also reflects sharply increased demand from developing country industrialization, especially in China. Markets for leading commodities remain cartelized (LeClair 2000), even after the collapse of price stabilization schemes in the 1980s, but the effects of this on prices and depletion rates remains unclear. Recent price rises are unlikely to reflect significantly increased scarcity, with estimated reserves ample relative to demand (Tilton 2003). The longer term trends of demand for resources have largely continued of sluggish growth in demand (with primary energy sources) or little trend growth (with metals). In this sense the demand problems that have faced resource exporters in the 1980s and 1990s are likely to continue. Cyclical factors continue to be particularly important, both on the demand and supply side and the potential for short run price rises is evident for some metals. The safest prediction is that cyclical factors will continue to dominate

[TABLE 11 ABOUT HERE]

Earlier evidence indicated that energy prices played a significant causal role in postwar economic activity amongst developed economies and this appears to be the case for commodity prices in general (Labys and Maizels 1993). The early 1980s collapse in commodity prices played a key role in reducing developed country inflation and laying the basis for subsequent expansion (Beckerman and Jenkinson 1986). The ability of the US and other economies to sustain expansion over the 1990s without igniting inflation was underpinned in part by continued low commodity prices; thus low commodity prices played a role in sustaining the 1990s new economy boom. As noted above, recent macroeconomic forecasting models frequently don’t examine the direct effects of higher energy (or commodity) prices on output and focus instead on their inflationary impacts. Although the resource intensity of GDP has fallen it remains unclear precisely how commodity prices contributed to sustaining non-inflationary growth and what impact sustained higher energy and commodity prices would have on output and inflation amongst developed economies even if the source of such price rises is as likely to come from increased demand by industrializing developing economies as from developed economies.

Overall the evidence for the leading metals does not support notions that a new economy based on ICT technologies is leading to reduced material intensity of production. In keeping with earlier patterns economic up-turns tend to increase demand for materials in the short run at least since equipment and construction are relatively intensive in the use of materials. After sharp declines in metals prices in the 1980s and early 1990s they showed signs of recovery in this decade with rising demand for aluminum and copper in particular. One can thus concur with Tilton’s conclusion before the rise of the new economy that although the metals intensity of income has declined, growth has not been decoupled from metal resources (Tilton 1989).

5. Global Dimensions

One obvious question here is whether trade specialization has meant that developed economies have reduced their domestic resource use but increasingly source this from abroad instead. If this was the case then derived demand for natural resources would be satisfied by overseas production, but the effective resource intensity of GDP (and its growth) would have fallen by less than these figures would indicate.

This can partly be addressed by updating the analysis of Atkinson and Hamilton (2002). They examined the difference between resource depletion in various countries and that once adjusted for an ‘ecological balance of payments’, the depletion accounted for by domestic absorption. Assuming that production of traded goods depletes resources at the same rate as national income, then exports are netted out of this depletion but the derived impact of imports on resource depletion in the source country is added in. Such an analysis is subject to two key limitations, both of which are likely to bias estimates of the impact of domestic absorption on depletion downwards: first, in assuming that a country’s exports deplete resources at the average rate for national income, whereas for resource exporters in particular the export sector is likely account for more than an average share of depletion; second, this approach cannot account for the derived demand effect where imports from one country have been produced using depleted resources imported from a third country. Nevertheless, in the absence of detailed input-output data for many countries this approach can provide an approximate indicator of the global impact on resource depletion of domestic economic activity. Recent advances in green national accounting means that estimates of domestic resource depletion are readily available; the average (national income-weighted) global rate of depletion fell slightly on these figures from 4.1 to 3.8 per cent of global income over this period; nevertheless, this is still above one per cent figures often suggested. These are presented for sample countries in table 12; they show no clear pattern over the 1990s.

[TABLE 12 ABOUT HERE]

These adjustments do not make a dramatic difference to depletion rates in these economies, although it does reduce the dispersion amongst this group. Australia shifted from being a net resource depletion exporter to importer over this period; reforms to the economy over this period saw a shift away from resource-based industries. Canada has a relatively high rate of resource depletion by developed country standards and this rose during the 1990s; it was also the only one of this sample that was consistently a resource depletion exporter over this period. The relatively high depletion import figures for Finland and Sweden largely reflect their high level of trade with Russia. Whilst acknowledging the caveats with this analysis, it does not indicate that low rate of depletion amongst developed economies simply reflect displacing this onto other economies through trade. It is not surprising that this adjustment makes relatively little difference to the impact of these economies on resource depletion since most of developed countries trade is with other developed countries which typically have low rates of resource depletion. Resource exporters may still be depleting their deposits at unsustainable rates in order to earn foreign exchange in the face of prices that do not fully reflect social costs.

6. Conclusions

This paper has examined whether the new economy based on ICT economies has led to a “weightless world” in the sense of significantly reducing the material content of production. The conclusion is largely negative. The expansion of the services sector is not clearly leading to a growth of a dematerialized weightless sector as much of the services sector remains associated with goods production. The energy intensity of

GDP in developed economies has declined in the 1990s but this is largely a continuation of earlier trends. The relative growth of sectors that produce ICT goods or use them intensively do not appear to explain much of the decline in energy-GDP intensities amongst the largest new economy countries. Nevertheless, much of the growth in demand for energy is driven by the transportation and residential sectors rather than growth in production of goods and services. It remains unclear, though, whether this is driven by continuous technical progress (and structural change) more or less associated with economic growth processes or whether it is driven by discrete changes in energy efficiency. If the latter is the case then forecasting future demand is rendered particularly problematic. It seems likely, though, that developed country demand will continue to grow as demand rises from industrialization in key developing economies. With short term limitations of capacity and possible longer term supply constraints this is likely to increase the importance of strategic interaction between major oil producer and consumer nations, although the dynamics of this relationship are not predetermined.

With demand for the major metals, again there was considerable ambiguity as to whether there were clear declines in demand for these over time or discrete changes at key intervals. In general it does not appear either that growth of income in developed economies has a simple link with resource demand or that the technological processes driving growth in these economies is clearly associated with greater resource efficiency and declining material content. Technology does offer possibilities for enhanced efficiency in resource use – and, associated with this, moderating the emission of green house gases – but this is not automatic and requires supporting institutions and public policy.

As noted at the outset, predictions about the future demand and supply of resources have been fraught with dangers. Claims that structural changes will substantially reduce the material content of production have often turned out to be overstated; authors have often overlooked that declining content is still consistent with rising absolute consumption levels. The evidence does not point to resource demands simply being displaced onto importing countries, although this needs further investigation. Nevertheless, the low commodity prices that have helped limit inflation during upturns over the past two decades show signs of coming to an end. Resources may have a more significant impact on output and inflation in the 21st century than they had at the end of the 20th.

Appendix: Data Sources

Real GDP (1995 US$, PPP basis) – OECD, *Economic Outlook*, data CD-ROM.

Total Primary Energy Supplies – OECD/IEA, *Energy Balances of OECD Countries*, various issues.

World and US metals consumption data from US Geological Survey database online at: http://minerals.usgs.gov/minerals/

Industrial production, producer prices deflators and metals price indices – IMF, *International Financial Statistics*, various issues; except US metals prices (and world steel prices) from USGS database. Industrial countries industrial production and producer prices indices used as proxies for world values.

Resource depletion – World Bank, World Development Indicators online database.

Imports by origin – IMF, Direction of Trade Statistics on line database.

Canadian sectoral energy consumption data from Natural Resources Canada: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/home.cfm?text=N&printview=N

UK sectoral fossil fuel energy consumption data from Office of National Statistics Environmental Accounts: http://www.statistics.gov.uk/CCI/nscl.asp?ID=6805

US sectoral fuel consumption data from Energy Information Administration: http://www.eia.doe.gov/emeu/mer/consump.html

Canadian and UK sectoral output data from OECD STAN data CD-ROM; US sectoral output data is from Bureau of Economic Analysis Industry Economic Accounts: http://www.bea.gov/bea/dn2.htm

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Table 1: Shares in total value added of market activities OECD Countries, 1990-2000

	1990	2000
Goods	35.9	33.8
Services linked to goods production	39.5	41.9
Free-standing services	25.0	24.9

Source: Calculated from OECD*, National Accounts of OECD Countries: 1970-2000, Volume 2: Detailed Tables*, using classifications from Blades (1987). Shares are in constant price terms.

Table 2: Percent Share of ICT Investment in Non-Residential Investment, 1990-2000

		Australia	Canada	Finland	France	Germany	Italy	Japan	UK	US
IT Equipment	1990	5.5	4.5	3.6	3.5	5.5	4.2	3.8	6.0	7.0
	1995	8.4	5.7	4.0	3.9	4.6	3.5	4.6	8.6	8.7
	2000	7.2	7.9	2.9	4.4	6.1	4.2	5.2	8.4	8.3
Communication Equipment	1990	3.8	3.8	3.9	3.2	4.8	5.7	4.0	2.0	7.5
	1995	4.7	4.0	9.3	3.5	4.2	6.7	5.3	3.6	7.3
	2000	5.6	4.2	15.3	3.9	4.3	7.2	6.9	3.6	8.0
Software	1990	4.6	4.9	5.2	2.6	3.7	3.8	3.1	2.1	8.0
	1995	6.4	7.1	9.2	3.5	4.5	4.3	4.0	3.5	10.1
	2000	9.7	9.4	9.8	6.1	5.7	4.9	3.8	3.0	13.6

Source: Cohen *et al*. (2004: 22)

Table 3: Energy Consumption-GDP Ratios, 1960-2003

	1960	1973	1980	1990	1995	2003
Total energy consumption:			(Millions of tonnes oil equivalent)			
Australia	31.55	57.62	70.37	87.54	94.38	112.65
Canada	76.27	159.84	193.00	209.09	231.74	260.64
Denmark	9.03	19.83	19.78	17.58	20.05	20.76
Finland	9.78	21.35	25.41	29.17	29.63	37.55
Ireland	3.78	7.19	8.49	10.57	11.36	15.09
Sweden	20.54	39.32	39.91	46.66	50.00	51.53
UK	160.46	220.72	201.28	212.18	223.18	231.95
US	1021.4	1736.5	1811.7	1927.6	2088.5	2280.8
Energy-GDP ratios:						
Australia	30.27	28.78	29.32	26.60	24.98	22.44
Canada	46.14	42.63	40.29	33.23	33.82	28.98
Denmark	19.15	23.20	21.24	16.15	16.71	14.56
Finland	29.54	34.40	33.94	28.86	30.66	29.55
Ireland	24.45	27.18	23.32	20.34	17.39	12.51
Sweden	27.61	31.22	27.81	26.31	27.45	23.06
UK	32.01	30.32	25.79	20.95	20.29	17.07
US	42.97	42.93	37.68	29.29	28.22	23.93

Source: See appendix

Table 4: Rates of Change in Energy-GDP Ratios, 1973-2003

	1973-2003	1990 Break?	1973-1990	1990-2003
Australia	–0.39	4.11**	–0.38	–0.60
Canada	–0.54	4.74**	–0.64	-0.68
Denmark	–0.67	1.82		
Finland	-0.21	2.63*	–0.40	–0.32
Ireland	–0.97	33.11***	–0.59	–1.68
Sweden	–0.37	5.23**	–0.25	–0.70
UK	–0.77	14.48***	–0.95	–0.85
US	–0.84	20.94**	–1.09	–0.72

1990 Break – Chow test for structural break in trend series
***, **, * - significance tests at 1, 5, 10 per cent levels

Source: See appendix

Table 5: Sectoral Contributions to Energy Consumption Growth, 1990-2000

	Transportation	Residential
Australia	43.0	13.5
Canada	115.3	15.2
Denmark	34.3	8.6
Finland	7.6	-2.2
Ireland	61.4	12.5
Sweden[1]	86.5	-76.4
UK	52.0	43.1
USA	62.3	17.5

1. 1993-2000

Table 6: Decomposition of Change in Energy Intensity of Value Added, 1990-2000

	Canada	UK	USA[1]	USA (excl petrol)
Change in Energy Intensity	-14.6	-17.3	-5.0	-5.4
Change Due to:				
Structural Change	-3.1	-4.8	16.5	-6.5
Sectoral Intensities	-8.2	-11.6	-12.3	1.1
Interaction Effect	-3.3	-0.9	9.2	0.0
Percentage due to:				
ICT sectors	31.5	7.0		4.0

1. 1991-1998

Table 7: Error Correction Estimates of World Demand for Metals, 1957-2002

		Aluminum	Lead	Steel	Zinc
Short-run adjustment parameters	β_1	0.99	0.48	1.11	0.97
		(6.30)***	(2.76)***	(8.58)***	(5.47)***
	β_2	0.04	-0.02	0.04	-0.06
		(1.17)	(-0.53)	(0.33)	(-1.85)*
	β_3	-0.12	-0.44	-0.10	-0.44
		(-0.96)	(-3.47)***	(-1.10)	(-3.40)***
Long-run equilibrium parameters	α_0	4.64	4.88	6.76	5.18
		(47.53)***	(43.93)***	(60.57)***	(48.52)***
	α_1	1.41	1.10	1.26	0.92
		(20.18)***	(13.29)***	(14.30)***	(12.42)***
	α_2	0.05	-0.03	0.02	-0.08
		(1.31)	(-1.03)	(0.20)	(-2.83)***
	α_3	-0.001	-0.01	-0.01	-0.002
		(-1.12)	(-10.40)***	(7.06)***	(-2.02)**
R^2		0.99	0.89	0.97	0.98
DW		1.83	1.28	1.44	1.61
LM1		1.78	3.03*	0.78	1.19
ARCH		3.46*	0.27	0.49	0.17
JB		2.78	4.84*	7.52*	1.68
CHOW(73)		9.64***	1.66	5.57**	1.50
CHOW(80)		6.23***	2.67**	2.50**	0.64
CHOW(90)		0.73	7.28***	2.86**	0.96

DW is the Durbin-Watson statistic; *LM* is the F-Form of the Breusch-Godfrey test for a second order serial correlation process in the residuals; *ARCH* is the F-Form of the LM test for a first order ARCH process in the residuals; *NORM* is the Jarque-Bera test for normality of the residuals distributed as $\chi^2(2)$; *CHOW* is the F-Form of the Chow forecast test for parameter stability with a break-point in 1973, 1980 and 1990. Significance levels: ***, **, * - 1, 5, 10 per cent levels. *t*-statistics in parentheses.

Table 8: Estimates of World Demand for Metals, 1957-2002

	Copper	Tin
γ_0	0.13	0.72
	(0.27)	(1.48)
γ_1	0.64	1.03
	(4.41)***	(3.13)***
γ_2	-0.03	-0.16
	(-0.32)	(-1.68)
γ_3	0.04	0.07
	(0.48)	(2.11)**
γ_4	0.01	0.01
	(0.35)	(0.82)
R^2	0.35	0.29
DW	1.71	1.52
LM1	0.53	1.21
ARCH	0.91	8.78***
JB	7.33**	0.67
CHOW(73)	2.95**	2.07*
CHOW(80)	1.69	4.57***
CHOW(90)	3.04**	5.18***

Key: see table 8

Table 9: Error Correction Estimates of US Demand for Metals, 1950-2002

		Aluminum	Steel
Short-run adjustment parameters	β_1	0.99 (6.30)***	2.33 (13.11)***
	β_2	0.04 (1.17)	-0.07 (-0.37)
	β_3	-0.12 (-0.96)	-0.22 (-3.22)***
Long-run equilibrium parameters	α_0	4.47 (21.65)***	6.30 (23.97)***
	α_1	1.59 (20.24)***	1.56 (6.97)***
	α_2	-0.33 (-2.57)***	-0.37 (-2.30)**
	α_3		-0.02 (-6.78)***
	α_4	0.001 (0.62)	
	α_5	-0.01 (-5.70)***	
R^2		0.95	0.51
DW		1.89	1.64
LM1		1.01	1.62
ARCH		1.59	0.56
JB		1.95	3.73
CHOW(73)		-	1.91
CHOW(80)		-	3.11**
CHOW(90)		-	2.36*

Key: see table 8

Table 10: Estimates of US Demand for Metals, 1950-2002

	Copper	Lead	Tin	Zinc
γ_0	2.90	2.61	1.19	1.74
	(6.24)***	(4.09)***	(2.39)**	(5.06)***
γ_1	1.94	1.47	1.50	1.74
	(11.33)***	(3.79)***	(3.60)***	(9.62)***
γ_2	-0.53	-0.49	-0.26	-0.29
	(-6.42)***	(-4.31)***	(-2.87)***	(-4.89)***
γ_3	0.24	0.17	-0.04	0.07
	(6.16)***	(3.25)***	(-0.71)	(3.61)***
γ_4	0.01	0.07	0.03	-0.11
	(0.20)	(0.89)	(0.63)	(2.55)***
R^2	0.81	0.44	0.36	0.73
DW	2.43	2.15	2.48	1.87
LM1	2.15	0.51	2.59*	0.25
ARCH	0.00	5.66**	1.68	1.72
JB	2.32	0.31	0.23	0.80
CHOW(73)	0.71	3.25**	1.03	2.98**
CHOW(80)	2.15*	2.36**	1.01	1.75
CHOW(90)	0.92	0.76	0.65	0.29

Key: see table 8

Table 11: Indices of Metals Prices, 1974-2005 (2000=100)

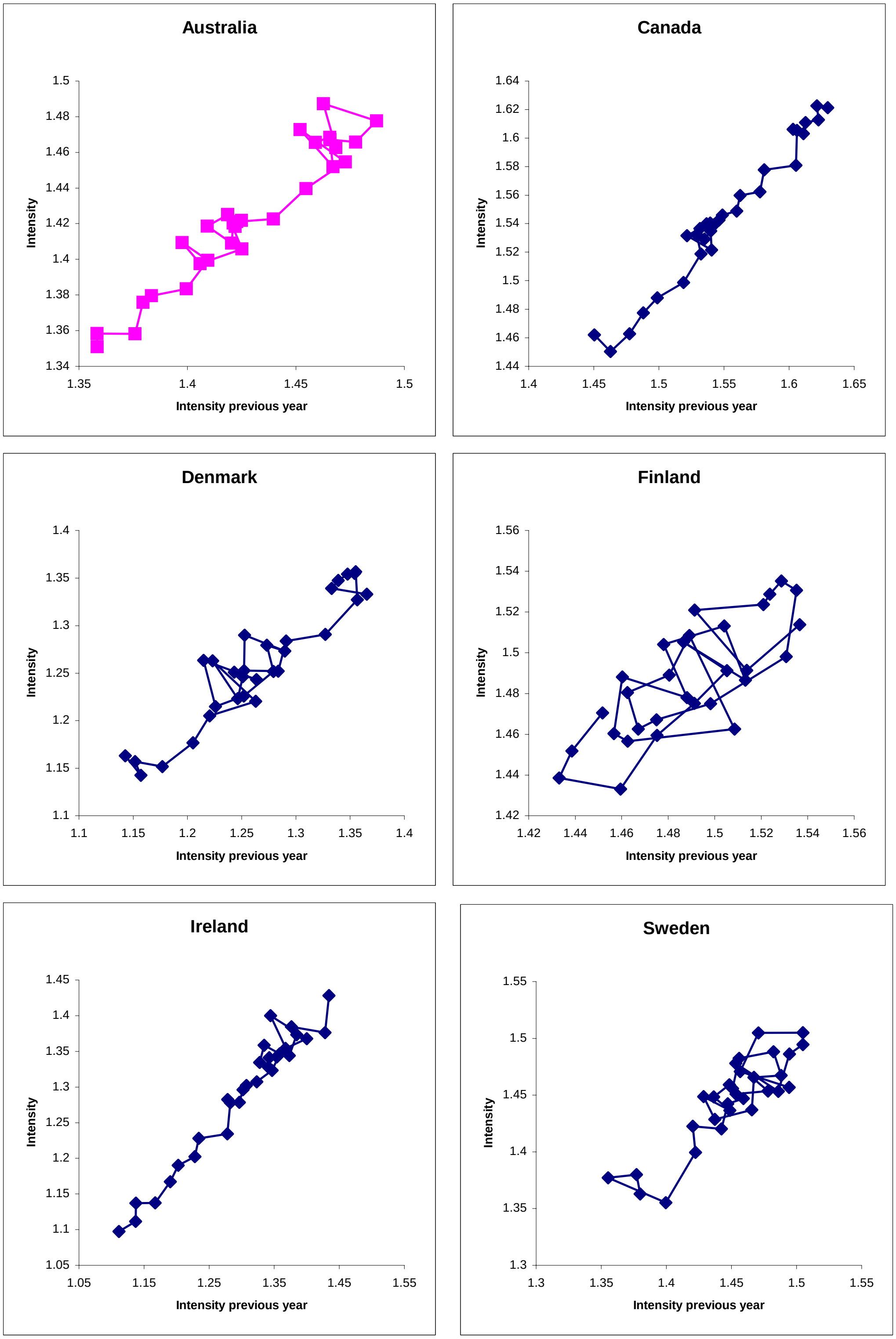
	All Metals	Aluminum	Copper	Lead	Tin	Zinc
1974	78.7	49.3	113.3	130.1	150.6	109.7
1980	119.0	114.4	120.4	199.3	308.6	67.5
1990	120.0	105.7	146.7	178.2	111.9	134.6
2001	90.2	93.2	87.1	104.9	82.6	78.6
2002	87.7	87.1	86.0	99.6	74.7	69.1
2003	98.4	92.4	98.1	113.2	90.0	73.4
2004	134.0	110.8	157.8	194.2	156.0	92.9
2005*	164.4	118.6	191.1	209.3	141.6	114.8

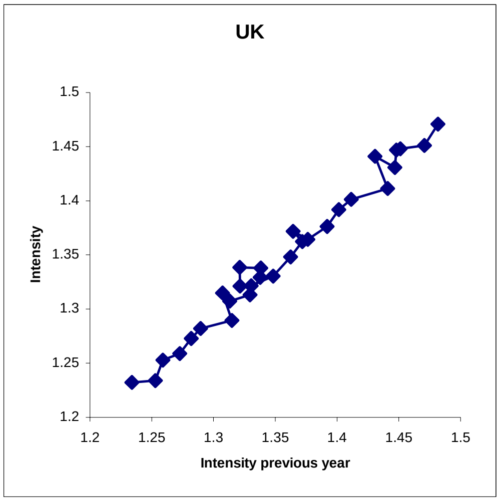
* First three quarters

Table 12: Ecological Balance of Payments, 1990-2000

	Energy Depletion	Mineral Depletion	Total	Depletion Exported $ millions	Depletion Imported $ millions	Adjusted Total Depletion
Australia						
1990	1.38	2.05	3.42	1332.6	1094.6	3.33
2000	1.81	1.53	3.34	2108.5	2166.7	3.35
Canada						
1990	2.60	0.67	3.27	4134.8	2703.0	2.98
2000	4.93	0.18	5.11	14061.9	5139.6	4.02
Denmark						
1990	0.30	0.02	0.32	108.9	496.6	0.70
2000	0.87	0.00	0.87	441.6	727.3	1.06
Finland						
1990	0.00	0.05	0.05	13.3	890.4	1.04
2000	0.00	0.02	0.02	9.2	1637.9	1.27
Ireland						
1990	0.17	0.28	0.45	107.0	204.0	0.69
2000	0.05	0.10	0.15	114.5	558.7	0.59
Sweden						
1990	0.00	0.26	0.26	138.0	877.5	0.74
2000	0.00	0.07	0.07	61.5	1382.5	0.65
UK						
1990	0.72	0.00	0.72	1332.7	3889.2	0.97
2000	1.15	0.00	1.15	3252.3	6330.2	1.34
US						
1990	1.49	0.07	1.56	6132.5	27143.4	1.92
2000	1.15	0.02	1.17	9032.3	63754.3	1.73

Figure 1: Connected Scatter Plots of Energy Intensities, 1973-2003

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Intensity
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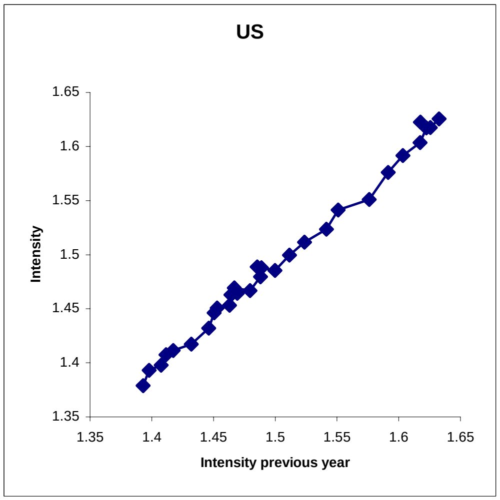
1.45
1.4
1.35
1.3
1.25
1.2
1.2
1.25
1.3
1.35
1.4
1.45
1.5
Intensity previous year


US
Intensity
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.35
1.4
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1.5
1.55
1.6
1.65
Intensity previous year

Figure 2: World Intensity of Use of Main Metals

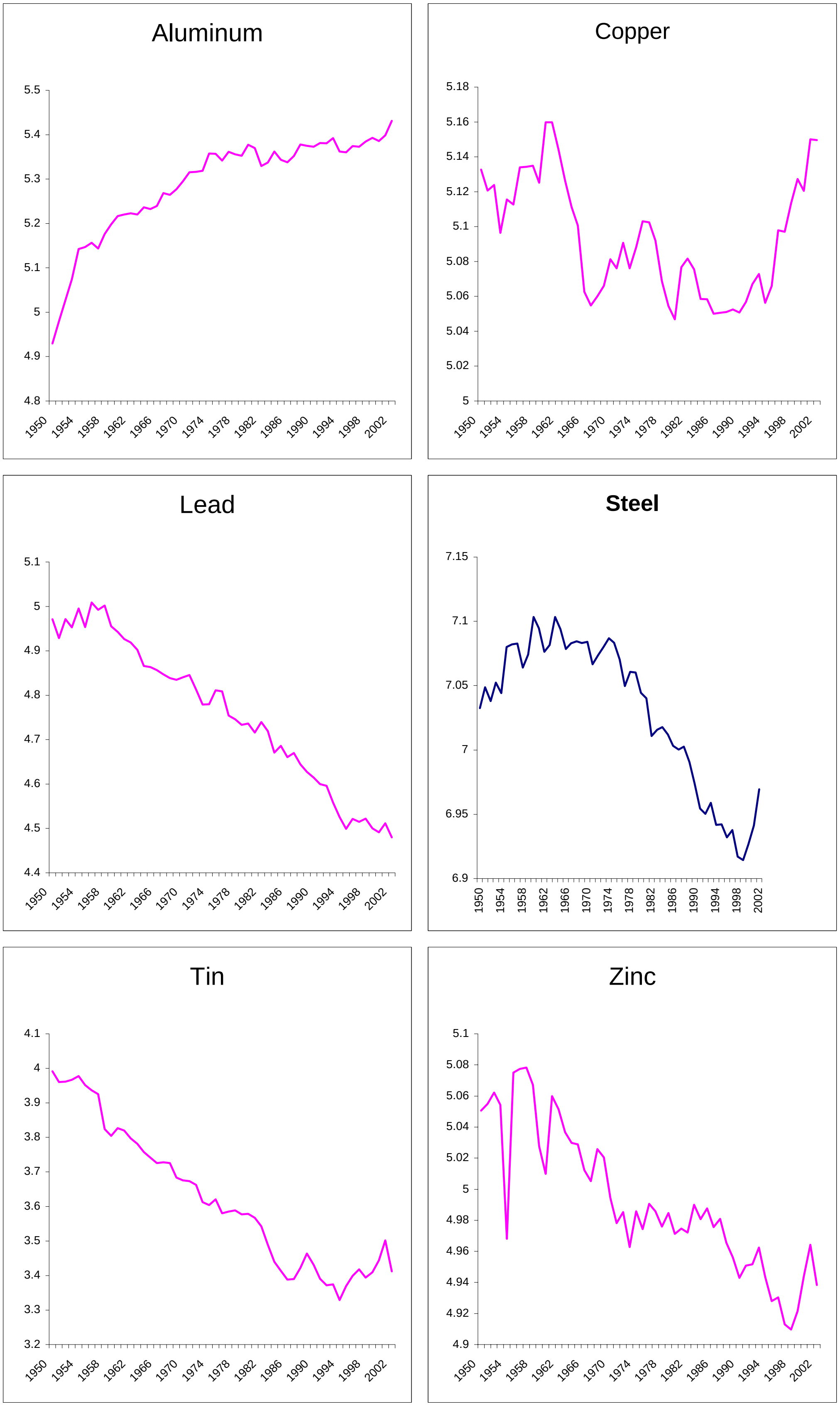

Figure 3: US Intensity of Use of Major Metals

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[1] This pessimistic prediction lay behind Thomas Carlyle's oft-cited characterisation of economics as "the dismal science".

[2] See further the special issue of *Ecological Economics*, vol. 22 no. 3 (Sept 1997).

[3] Note that the success of Scandinavian economies in ICTs indicates that the new economy is not limited to deregulated market economies but is also compatible with market economies characterized by centralized wage bargaining systems and extensive welfare states financed by relatively high taxation levels.

[4] Although some have claimed that direct use of ICT equipment gives rises to significantly increased electricity demand, this appears to be based on faulty estimates (Laitner 2003).

[5] Some authors have pointed out that all work is applied effort and therefore requires energy. Whilst this must be true from the laws of physics it still leaves open precise elasticities in relation to particular energy inputs and product outputs. More fundamentally, there are formidable problems in deriving an economic value theory from energy concepts, as Mirowski (1988; 1989) has explored in detail.

[6] From: Energy Indicators, *OPEC Review*, Vol. 28 No. 4 (December 2004).

[7] These assessments are based in part by analysis from former oil company geologist Colin Campbell available at:
http://www.mbendi.co.za/indy/oilg/p0070.htm

[8] Supplies of natural gas are estimated to be greater than for petroleum and it has considerable potential as a "bridge fuel" to reduce reliance on oil; but its location tends to be closely related to petroleum and there are greater logistic difficulties in its transportation and use. The controversial nature of nuclear power hardly needs stating. Potential energy from renewable sources is unlikely to provide more than a fraction of current energy demand in the near future.

[9] See Adam Porter, 15th July 2005. How much oil do we really have?
http://news.bbc.co.uk/1/hi/business/4681935.stm

[10] A copy has been posted online: Robert L. Hirsch, Roger Bezdek and Robert Wendling, February 2005. Peaking Of World Oil Production: Impacts, Mitigation, & Risk Management. US Department of Energy. Available at: http://www.hubbertpeak.com/us/NETL/OilPeaking.pdf

[11] This was estimated for all metals where a cointegrating relationship was indicated, but in all other cases did not significantly improve the fit of the estimation.