

**House of Representatives: Inquiry into raising the level of  
productivity growth in the Australian economy**

Submission title: The importance of the role of energy in productivity  
measurements\*

---

\*

Dr Judith McNeill  
Institute for Rural Futures  
University of New England  
Armidale NSW 2351

---

**UNE**  
UNIVERSITY OF  
NEW ENGLAND



INSTITUTE FOR  
**Rural Futures**



# House of Representatives: Inquiry into raising the level of productivity growth in the Australian economy

## Submission title: The importance of the role of energy in productivity measurements\*

\*Dr Judith McNeill, Research Program Leader, Institute for Rural Futures, University of New England, Armidale, NSW.

This submission is addressed to part (c) of the Terms of Reference:

*(c) the adequacy of productivity growth measures.*

It also has implications for part (j) of the Terms of Reference:

*j) the key reforms and measures that can be undertaken to lift Australia's permanent rate of productivity growth.*

## Summary

This submission reports on recent research findings regarding the factors that contribute to productivity growth. It draws particular attention to the findings of interdisciplinary research teams (scientists and economists) in Europe and the United States regarding the critical role played by energy in influencing past productivity growth in developed countries. In past analyses of productivity trends, energy is not normally considered separately, as a factor of production. Separate inclusion of the role played by different sources of energy (in the sense of the ability of these sources to perform work) over many decades, does not contradict the insights of previous studies regarding the importance of other factors such as human ingenuity, knowledge or 'human capital',

adequacy and efficiency of economic institutions and so forth. It shows instead, how such factors have combined with machines (capital) and labour to lower dramatically the per unit costs of energy, thereby facilitating much higher levels of output. The research is able to explain past trends in productivity remarkably well, but in so doing contains a concerning warning for the future.

## **1. The role played by energy in past productivity increases: why it has been overlooked.**

Robert Solow's studies of 1956 and 1957 contributed the theoretical foundations for measuring productivity.<sup>1</sup> Although refined and improved in other ways in later studies, it has remained a useful metaphor to approach productivity measurement by imagining that the entire economy has a single production function, as would an individual firm, that combines the factors of production labour (L), and capital (K), together with a technology (A) to produce economic output (Y). The way the factors are combined in the theory can be as a 'Cobb Douglas' production function or it can be a more sophisticated and realistic mathematical form.<sup>2</sup> Generally speaking, the framework is known as the neoclassical approach to productivity measurement.

The startling finding of Solow's 1957 study was the significance of the technology parameter (A) in real world testing of the model. Increases in labour and capital, measured over the period 1909 to 1949, could explain only 10 per cent of the observed growth in the United States economy over that period. The remaining 90 per cent, Solow attributed to 'technical progress' (A), now called 'total factor productivity', which is assumed to grow as a constant

---

<sup>1</sup> Solow, Robert M. (1956) 'A contribution to the theory of economic growth', *Quarterly Journal of Economics*, 70, 65-94; Solow, Robert M. (1957) 'Technical change and the aggregate production function' *Review of Economics and Statistics*, 39, 312-320.

<sup>2</sup> Appendix F Theoretical Underpinnings, to the United Kingdom Cabinet Office paper *Resource productivity: making more with less*, (Performance and Innovation Unit, United Kingdom, 2001) contains an 'entry level' explanation of the Solow framework for measuring productivity.

rate each year,  $A(t)$ . The key point is that  $A$  is 'exogenous' – it cannot be explained from within the theoretical model – which means that the main driving force behind economic growth could not be explained in Solow's study. The large 'gap' in the explanatory power of the model became known as the 'Solow Residual'. Subsequently, many decades of research have set about attempting to devise and test models that might throw light on the Solow Residual.<sup>3</sup>

Any theory necessarily omits features of the real world in order to make models manageable. It is hoped by theorists that omitted variables are minor influences. One variable that has been omitted in most productivity theory and measurement studies is energy.

Energy may have been overlooked in prior studies largely because as a factor of production, it is cheap compared to capital and labour. It is a feature of the neoclassical approach to productivity measurement that the relative cost of a factor of production influences the weight that factor carries in explaining output growth<sup>4</sup>. Energy may have been omitted also because a key focus of

---

<sup>3</sup> For excellent surveys of the research undertaken see (chronologically): Nadiri, M. Ishaq (1970) 'Some approaches to the theory and measurement of total factor productivity: A survey', *Journal of Economic Literature*, December, 84 (4), 1137-77; Nelson, R. (1981) 'Research on productivity growth and productivity differences: Dead ends and new departures', *Journal of Economic Literature*, September, XIX, 1029-1064; and Lipsey, R. and Carlaw, K. (2004) 'Total factor productivity and the measurement of technological change', *Canadian Journal of Economics*, 37(4), 1118-1150.

<sup>4</sup> The internal logic of homogeneous production functions and perfect competition assumptions requires that the output elasticities – the percentage change in output due to a one percentage point change in one of the variables in the production function – are weighted by their factor costs. Since energy is significantly cheaper than either labour or capital, this understates the importance of energy in a production process.

economic inquiry in the past has been the *distribution* of the national income – how much does labour get, and how much does capital get, and why? A production function was therefore seen primarily as a relationship between labour and capital where there was opportunity to *substitute* between these two factors depending on their relative prices. It was not seen the way physicists see it – applying energy, using labour and capital, to *transform* raw material (or intermediate goods) into more economically useful or desirable forms, including economic services to others.

## **2. Energy as a third factor of production in productivity measurement: the results of new research.**

Research teams, with expertise spanning the natural sciences as well as economics, have found that when energy is included in production functions as a third factor of production, a good deal of the Solow Residual can be explained<sup>5</sup>. The way in which energy is defined and included in production functions differs slightly between studies, but the key idea behind the approach captures the ability of evolving forms of energy to be able to perform greater amounts of work over the decades. Ever more goods and services are produced as increasingly effective forms of energy are combined with machinery (capital) and labour. As a simple illustration, food was produced in

---

Actually, it is difficult to think of a production process that could take place *without* energy of some sort (including solar), so that the problem here is rather like the famous ‘diamonds versus water’ paradox: energy is vital, but cheap because it has been plentiful (at least in the past).

<sup>5</sup> Prominent examples are Kummel, R., Henn, J., and Lindenburger, D. (2002) ‘Capital, labor, energy and creativity: modelling innovation diffusion’, *Structural Change and Economics Dynamics*, 13, 415-433, (building on many earlier works by R. Kummel); and Ayers, R.U. and Warr, B. (2009) *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*, Edward Elgar, UK Cheltenham, (again building on many earlier studies by Ayres, R. U and by Ayres and Warr).

hunter-gatherer societies using ‘the energy of each individual’s muscular activities and the force concentrating technologies of spear points and blades’<sup>6</sup> Energy from human and animal muscles, wood, elevated-water, and then coal were used as societies grew; until at the beginning of the twentieth century, the discovery of oil (and its derivatives), with its even greater energy intensity and transportability, transformed the economic landscape on a scale economic hitherto unimaginable. This was especially so, of course, as the discovery of oil combined with the invention of the gasoline-powered internal combustion engine. As Hall *et.al* say, ‘huge armies of energy slaves (now) create our wealth’.<sup>7</sup>

In their recent studies, Ayres and Warr (2009) calculate the useful work done by energy (U), taking into account improvements in its efficiency of use, and include this in their production function, to account well for economic growth in the USA, UK and Japan over the twentieth century. Their findings do not contradict the sensible suggestions of many earlier studies that technical progress is due to ingenuity, ‘learning by doing’, human capital, accommodating economic institutions and such like. Instead, Ayres and Warr (2009) suggest that factors like human ingenuity have combined with labour and machinery to produce ever more useful and efficient ways of *using energy* to produce ever greater numbers of goods and services. Ayers and Warr (2009) argue that for the first time in productivity studies, this approach ‘endogenises’ economic growth, by introducing a variable, the work done by

---

<sup>6</sup> Hall, C. and Klitgaard, K.(2006) ‘The need for a new biophysical paradigm in economics for the second half of the age of oil’, *International Journal of Transdisciplinary Research*, 1 (1), 13.

<sup>7</sup> Ibid.



energy, into a production function, along with labour and capital, such that the model can then be tested empirically.<sup>8</sup> In the past, it has been difficult to find testable and replicable models, as are needed to substantiate theories.

### **3. The significance of the findings as regards future productivity trends**

The researchers reported in this submission believe that the procedures inherent in the neoclassical framework for measuring productivity, as originated by Robert Solow, and as used over many years since, have tended to create a 'blind spot' for economists as to the fundamental importance of energy productivity. A measure of the 'useful work' done by energy serves as a proxy to reflect technological progress, and it can reproduce observed economic growth without there being a Solow Residual left unexplained.

If economic growth in the future depends, as it has in the past, on continued declines in costs per unit of energy, it becomes critically important to ask whether it is realistic to expect a future the same as the past. Ayres and Warr (2009: 297) conclude that a slowing of economic growth rates is possible:

'The most important implication of the new theory, up to now, is that future economic growth is not guaranteed because the efficiency gains that have driven growth in the past may not continue. Economic growth depends on producing continuously greater quantities of useful work. This depends, in turn, upon finding lower-cost sources of exergy [useful work done by energy] inputs or more efficient ways of converting higher cost inputs into low-cost work outputs. In a world where the cheapest sources of exergy seem to be approaching exhaustion, the key to continued growth must be to accelerate the development of lower-cost alternative technologies, and policies, that increase conversion efficiency.

Meanwhile, if the rate of technological advance fails to compensate for the combination of approaching resource (notably cheap oil) exhaustion and policies needed to cut back on carbon dioxide emissions, we have to anticipate the possibility that economic growth will slow down or even turn

---

<sup>8</sup> The energy calculations and production function are not for the mathematically faint hearted.

negative. Global depression in the coming decades seems to us to be a serious risk.<sup>9</sup>

Scientists, Hall, Powers and Schoenberg (2008:109) draw a similar conclusion regarding the end of cheap petroleum in particular, and emphasise the need for accelerated investment in renewable energy technologies:

This cheap petroleum is finite and currently there are no substitutes with the quality and quantity required. Of particular importance to society's ...future is that depletion is overtaking technology in many ways, so that the enormous wealth made possible by cheap petroleum is unlikely to continue very far into the future. What this means principally is that investments will increasingly have to be made into simply getting the energy that today we take for granted...[T]he magnitude of the problem is enormous because of the scale required, the declining net energy supplies available for investment and the relatively low net energy yields of the alternatives. Given that this issue is likely to be far more immediate, and perhaps more important, than even the serious issue of global warming, it is remarkable how little attention we have paid to understanding it or its consequences.<sup>10</sup>

---

<sup>9</sup> Ayers, R.U. and Warr, B. (2009) *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*, Edward Elgar, UK Cheltenham, p297.

<sup>10</sup> Hall, C. A. S., Powers, R. and Schoenberg, W. (2008) 'Peak oil, EROI, investments and the economy in an uncertain future' Chapter 5 of D. Pimental (ed.) *Biofuels, Solar and Wind as Renewable Energy Systems*, USA, Springer, pp 109-132.