

Trevor Swan and the Neoclassical Growth Model

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Addressing an American Economic Association session celebrating the fiftieth anniversary of his 1956 “Contribution to the Theory of Economic Growth,” Robert Solow (2007, 3) issued a pointed reminder to his audience: “If you have been interested in growth theory for a while, you probably know that Trevor Swan—who was a splendid macroeconomist—also published a paper on growth theory in 1956. In that article, you can find the essentials of the basic neoclassical model of economic growth. Why did the version in my paper become the standard, and attract most of the attention?” The text of Solow’s address was published in the *Oxford Review of Economic Policy* in a special issue: “The Solow Growth Model.” The inattention that Trevor Swan’s model has suffered is underscored not so much by the title of the special issue, or the title of the present volume (which also refers only to Solow), but by the striking fact that neither the editorial preface nor any of the other seven articles cite Trevor Swan.

Some prominent publications provide notable exceptions.¹ In particular, two leading textbooks, Barro and Sala-i-Martin 2004 and Aghion and Howitt 1998, both refer to the “Solow-Swan” model (and not the “Solow” model) in their index section with sixty-one and twelve citations, respectively. Both Solow 1956 and Swan 1956 are included in the references. David Romer’s 2006 textbook is less generous to Swan, but he still

Barbara Spencer is Trevor Swan’s daughter.

1. We would like to thank Steve Dowrick and Robert Dixon for these exceptions.

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manages to mention the Solow-Swan model and Swan 1956 in a footnote (on page 7). In his introduction to the Penguin readings on growth economics, Amartya Sen (1970, 21, 30) refers to the Solow-Swan model and cites Swan 1956.² An indication of the relative prominence of Swan 1956 and Solow 1956 in the economic literature more generally is provided by a cited-reference search of the ISI Web of Science. As of March 2009, 401 publications cite Swan 1956 and 1,718 cite Solow 1956. Publications in the year 2000 or later represent 40 percent of Swan's citations (160 cites) and 46 percent of Solow's citations (798 cites). Apart from highlighting the current importance of growth theory, these numbers suggest that there has been only a small decline in the relative citation of Swan 1956 over time.

Swan's contribution initially won international academic recognition. He was a visiting professor at MIT in 1958, Irving Fisher Professor at Yale in 1962–63, and Marshall Lecturer at Cambridge in 1963.³ Swan 1956 was reprinted in Newman 1968, Williams and Huffnagle 1969, Stiglitz and Uzawa 1969, and, in part, Harcourt and Laing 1971. Nonetheless, and despite the generous efforts of Robert Solow himself (see, for instance, Solow 1997), Swan's work on growth theory has been overshadowed, at least outside Australia, by Solow's. Textbooks and classroom presentations typically discuss the steady-state equilibrium path of the neoclassical growth model in terms of the capital-labor ratio, as in Solow 1956, rather than the output-capital ratio, as in Swan 1956.

Who was Trevor Swan, what was his contribution to neoclassical growth theory, and how did it come to be eclipsed? Section 1 discusses Swan's background and early work, including his initial work on a growth model in 1950. Section 2 examines why Solow 1956 and Swan 1956 are viewed as independent contributions. Section 3 describes the Swan growth diagram. Section 4 discusses why Swan's work, including his diagram, has received less attention. Section 5 contains concluding remarks.

1. Swan's Way

Born in Sydney in 1918, Trevor Swan was a part-time student at the University of Sydney while working from 1936 to 1939 as a bank officer with the Rural Bank of New South Wales (see Butlin and Gregory 1989, Swan 2006,

2. Swan 1956 is referenced in two of the reprints in Sen 1970. Swan 1964 is reprinted, but does not reference Swan 1956 or Solow 1956.

3. Robert Solow gave the Marshall Lectures in the subsequent 1963–64 academic year.

and King 2007, 271–75 for biographical material, and Groenewegen and McFarlane 1990 for Australian economic thought). Despite the distraction of a full-time job, Swan received his bachelor of economics in 1940 with First Class Honours and with the University Medal and was appointed an assistant lecturer at the University of Sydney. At the age of only twenty-two, he immediately began publishing in the *Economic Record* on Australian war finance and banking policy (Swan 1940) and on the loanable funds–liquidity preference controversy over how the interest rate is determined (Swan 1941).

Wartime and postwar government service halted this promising early start on scholarly publication. From 1942, Swan was successively an economist in the Department of War Organization of Industry, secretary to the War Commitments Committee, chairman of the Food Priorities Committee, joint secretary of the Joint Administrative Planning Sub-Committee of the Defence Committee, chief economist of the Department of Post-War Reconstruction, and, from 1949, chief economist of the Department of the Prime Minister. Along the way, he was seconded to the UK Cabinet Office in 1947–48 (writing such memoranda as “Hicks on Budgetary Reform” and “The Theory of Suppressed Inflation,” plus three appendixes to “United Kingdom National Income, Output and Employment”) and to the U.S. Council of Economic Advisors in 1948–49 (where he wrote a series of memoranda on the supposed dollar shortage). He also accompanied Prime Minister Robert Menzies to London and Washington in 1950, negotiating a World Bank loan. As part of a group of experts appointed by the secretary-general of the United Nations, Swan helped write a 1951 report, “Measures for International Economic Security.”

Despite this heavy workload of public service, Swan managed to find time to write substantial review articles for the *Economic Record* on Oskar Lange’s Cowles monograph, *Price Flexibility and Employment* (Swan 1945, 1946), and on J. R. Hicks on the trade cycle (Swan 1950b). Even after leaving the Department of the Prime Minister in June 1950 to be the first holder of the chair in economics at the Australian National University’s Research School of Social Sciences,⁴ Swan served on the prime minister’s Committee of Economic Advice in 1955 and 1956 (and on the Board of the Reserve Bank of Australia from 1975 to 1985). Certain distinctive characteristics of Swan’s career are discernible: an economist fully engaged with cutting-edge macroeconomic theory but concerned about

4. See Cornish 2007 for details on the process of Swan’s appointment.

relevance to public policy, deeply rooted in Australian public life and academic discourse (he never published in a journal outside Australia) yet fully aware of developments in Britain and America (and in developing countries, taking part in a World Bank mission to Malaya that published its report in 1955 and leading the MIT–Ford Foundation mission to assist India’s five-year plan in 1958), and an economist who wrote more than he published.

In 1945, around the time of the Australian White Paper on Employment Policy, Swan wrote “The Principle of Effective Demand—a ‘Real Life’ Model” (published posthumously in 1989). This paper laid out the first macroeconomic model of the Australian economy. Characteristically, Swan opened his exploration of the inner workings of his Keynesian model with a quotation from Edgar Allan Poe’s “Maelzel’s Chess Player,” beginning with, “The interior of the figure, as seen through these apertures, appears to be crowded with machinery.” Solow (1997, 594–95) hails Swan’s 1945 paper as “a truly remarkable, precocious and pioneering exercise in empirical Keynesianism. . . . Apart from the *General Theory*, Swan’s guides are Lange’s 1938 translation into equations, Kalecki’s 1939 *Essays* . . . , Kaldor’s 1940 model of the trade cycle and even Pigou’s *Employment and Equilibrium*, but he puts them all to shame by virtue of the clarity of his thinking and his use of the macroeconomic data of the Australian economy, 1928–39, to give empirical substance to the analytical structure. . . . This combination of equilibrium thinking and sequence analysis is child’s play now. For the time, its 26-year-old author is producing a virtuoso performance. The model works and Swan’s commentary on it is very sophisticated.”

Solow (1997, 594) regards the Keynesianism of Swan 1989 and the neoclassical growth model of Swan 1956 “as a reminder that one can be a Keynesian for the short run and a neoclassical for the long run, and this combination of commitments may be the right one.” He reminds us that Swan (1956, 334) ended the opening paragraph of his neoclassical growth article by affirming, “When Keynes solved ‘the great puzzle of Effective Demand,’ he made it possible for economists once more to study the progress of society in long-run classical terms—with a clear conscience, ‘safely ensconced in a Ricardian world.’” Without rejecting the short-run Keynesian concerns of his 1945 paper (Swan 1989), Swan (1956, 335) assumed that “effective demand is so regulated (*via* the rate of interest or otherwise) that all savings are profitably invested, productive capacity is fully utilized, and the level of employment can never be increased merely by rais-

ing the level of spending.” Already in 1950, Swan (1950a) was prepared to assume full employment to analyze questions related to long-run growth. Also, in his policy advice in the early 1950s, Swan focused on problems of inflation and the balance of payments rather than unemployment, a concern illustrated by his opposition to import restrictions.⁵

While still chief economist in the Department of the Prime Minister, Swan (1950a) made his first venture into trying to reach some understanding of “the theory underlying any policy of economic development” with a sixteen-page memorandum titled “Size and Composition of Investment, and the Industrial Distribution of Labour in a Closed Progressive Economy.” Swan (1950a, 1) writes, “It cannot of course be proved that it is vital to understand the fundamental principles of our current actions—it may be quite sufficient in practice (and it is certainly easier) to tackle symptoms in an empirical commonsense sort of way—but there can be no harm in doing both. So far as I know, practically nothing has been done so far in this branch of theory [economic development]. The mathematicians have, I suggest, done something incidentally to enquiries which overlap this field, but if so I cannot understand them. A mathematician should, obviously, do this, but as none seems to have tried yet—I look you straight in the eyes—it may, as a very second best, be worthwhile to make a first shot of it in prose, with all the muddles and inaccuracies that involves.”

Although no formal mathematical model was written down, the discussion involved several formal assumptions, including “savings a constant proportion of income and unaffected by the rate of interest,” “complete mobility of labour,” “constant physical returns from land,” “full employment,” and “no inventions,” which were all included, at least as initial simplifying assumptions, in Swan 1956. Setting savings equal to investment, Swan (1950a, 5) reasoned using a simple numerical example that if capital and population is increasing at the same rate, then “the population increase will wholly exhaust net investment,” and capital and output per head will remain constant.⁶ In this case, the “increment of consumption

5. Swan (1951, 2–3) writes, “If we bring about this reduction [in consumption and investment] by directly restricting the *supply* of imports (by imposing quotas etc. . . .), the inflationary pressure of internal demand will be revived and increased. Without the safety valve hitherto provided by supplies from overseas, the whole economy might then blow up.” Later, Swan (1955, 2–3) writes: “Now they [import restrictions] imply acute problems of allocation, unofficial rationing, black-marketing, and some transitional unemployment for lack of materials.”

6. The capital stock is assumed to start at four times national income, which with a savings and net investment rate of 10 percent implies an initial 2.5 percent growth rate of capital (Swan 1950a, 2, 5).

demanded is an increment in the existing ‘average’ consumption in proportion to the rate of population increase” (5), but most of the analysis is concerned with a more complicated, but policy relevant case, in which marginal consumption as real income rises is biased toward specific uses, such as housing. Swan was concerned with the implications for living standards of the high allocation of capital to housing implied by a high rate of immigration to Australia.

Consumption goods were divided into three categories: houses, produced with capital alone; manufactures, produced with current labor and capital (in the form of machinery); and services, produced with current labor alone. The capital used to produce housing and manufactures embodies past labor services. Capital and labor are substitutable in the production of manufactures.⁷ However, given the difficulties of verbal analysis, it is not surprising that the general equilibrium effect of an increase in capital on relative factor prices and hence on the proportions of labor and capital in manufacturing is ignored.

In conclusion, Swan (1950a, 15) argues the approach in the paper “ought to provide a logical basis for analyzing the changes in industrial structure that we would wish to see today in Australia.” If researchers could determine basic magnitudes, such as “the ratios of capital to income, the precise investment requirements of population increase . . . we would know what industries (assuming constant prices and perfect mobility) we would wish to expand and how much and what industries ought to contract” (Swan 1950a, 15–16). His specific conclusion is of less interest than the fact that as early as January 1950, while still chief economist in the prime minister’s department, Swan was already experimenting with models of a growing economy with a given average (and marginal) propensity to save and mobile labor that is released into other sectors because of the substitution of capital for labor in manufacturing.

2. 1956 and All That

For those who knew Trevor Swan there is no doubt that he and Robert Solow each independently pioneered the neoclassical growth model. In

7. If the constant population desires only more manufactures, then all next investment is in machines, and “capital per head will rise steadily in manufactures, which will have constant current labor.” If it is services that people desire marginally, then all net investment is in machinery for manufactures, but the increase in capital per head and output per head in manufactures “means that manpower must be released from manufactures” to the production of services (Swan 1950a, 4).

particular, from Arrow, Chenery, Minhas, and Solow 1961 onward, Solow has repeatedly cited Swan's contribution to the neoclassical growth model, always treating Swan 1956 as an independent contribution (e.g., Solow 1997, 2007). Solow 1956 was published in February and Swan 1956 was published in December, giving Solow priority in terms of date of publication.

Swan first presented his growth model in an interdisciplinary seminar at the Research School of Social Sciences at the Australian National University (ANU) in June or early July 1956, circulating postseminar notes on 23 July with the title "Economic Growth," which were published posthumously as Swan 2002. According to John Pitchford, who had Swan as his PhD supervisor at the time, the seminar's official purpose was to discuss W. Arthur Lewis's *Theory of Economic Growth* (1955). Pitchford (2002, 382) reports that Swan was "rumoured to be working on something of significance on growth" and was asked to discuss Lewis's material on capital. "However, Trevor's responses to such requests were not always conventional." Instead, the economic historian Noel Butlin reluctantly gave a talk on determinants of saving and investment, and estimates of average capital-output ratios. "When Butlin had finished speaking Swan stood up and, by way of comment on Butlin's talk, gave us a version of his economic growth model." James Meade, who was a visitor at the ANU from May to September 1956, pronounced that "what we had just heard from Swan was a significant and original advance on received growth theory."

When did Swan become aware of Solow 1956? Pitchford (2002, 383) states that there was no mention by Meade or Swan of Solow 1956 during the 1956 seminar, and "the presumption from this must be that both were unaware of this paper at the time of the seminar." This view of the seminar and the independence of Swan's work is supported by Butlin and Robert G. Gregory (1989, 373–74), who refer to the model as the "Swan-Solow" model and also point out that as late as 1970 the growth model was taught at Yale as simply the "Swan Model." The journal issue with Solow's article reached Canberra in April 1956 (Pitchford 2002, 383n), but from 1955 through to the 1956 seminar, Swan was acting as a main economic adviser and close confidant of Prime Minister Menzies, so he could have easily missed it. With the positive response to his presentation, Swan would have been motivated to work further on his paper, which would naturally involve a check of the most recent literature. In postseminar notes, dated 23 July 1956, Swan (2002, 375n) mentions Solow 1956 in a footnote. Pitchford (2002, 383) recalls that these notes were produced some weeks after the seminar.

Solow became aware of Swan 1956 likely in March 1957. In a letter to Swan dated 1 April 1957, Solow writes, “I have just finished reading the article [Swan 1956] you so kindly sent me, and I must tell you that I can’t remember when I have enjoyed a piece of economics so much. It was sheer pleasure.”⁸ Swan’s visit to MIT in 1958 to lead the MIT–Ford Foundation mission to assist India’s five-year plan must have been arranged soon after that letter. Although we know of no direct documentation, Solow’s high opinion of Swan 1956 presumably influenced the invitation to Swan.

Although Solow and Swan each developed the essentials of what became known as the neoclassical growth model, their contributions were not identical. Indeed the very differences in their approaches help establish the independence of their contributions. There are a number of parallels in the history of the profession. Edward Chamberlin insisted that his monopolistic competition differed from Joan Robinson’s imperfect competition (see the introductions and appendixes to any later edition of Chamberlin 1933). The pamphlets that Thomas Robert Malthus, Sir Edward West, and David Ricardo published in February 1815 about rent and the Corn Laws were not identical (Malthus stressed the intensive margin, Ricardo the extensive margin of cultivation). There were distinctions among the marginal utility theorists of the early 1870s—William Stanley Jevons, Carl Menger, and Léon Walras—as displayed by William Jaffé (1976). Evsey Domar (1946) had an exact counterpart to the warranted rate of growth of Roy Harrod (1939), but not to Harrod’s natural rate of growth (Ahmad 1991, 87). Yet it is still meaningful to speak of the imperfect competition revolution of 1933, the classical theory of rent, the rise of marginalism in 1871–74, or Harrod-Domar growth theory.

The two pioneers of the neoclassical growth model, although finding much to admire in each other’s contributions, did not completely endorse every aspect of each other’s work: Solow (2007, 4) states that his 1956 article “didn’t get lost in the complications and blind alleys that beset Trevor Swan’s approach,” while the first footnote of Swan’s (2002, 375n) postseminar notes concludes: “Warning: Solow’s article is in several respects misleading.” Pitchford (2002, 385) explains that “‘misleading’ in this context is a matter of approach, one might even say of taste in that

8. Solow goes on to praise Swan’s appendix, “Notes on Capital,” and also states that he has two minor reservations about the first part of the paper, arising from the lack of generality of the Cobb-Douglas production function. We are indebted to Will Hansen at the Rare Book, Manuscript, and Special Collections Library at Duke University for this letter.

one's own expositional devices seem easier to work with, and of course did not imply that Swan thought Solow was wrong."⁹ Barbara Spencer recalls that one concern of her father was that subsequent researchers might use Solow 1956 to derive naive empirical estimates that were misleading as to appropriate policy.¹⁰ Swan (1956) also applied the term "misleading" to claims that Harrod's growth theory had a "knife-edge" equilibrium, and quoted Harrod (1948) on the progressive decline of the interest rate (and hence the marginal product of capital, as capital intensity rose) until the warranted growth rate equals the natural growth rate. Swan references Robinson (1956, 405) here, but not Solow, which suggests that he had written this material prior to reading Solow 1956.¹¹

Harrod 1939 and Domar 1946 were interpreted by Solow (1956) and many others (but not by Swan 1956) as assuming fixed-coefficient production technologies that gave their models knife-edge equilibria (also referred to as "razor-edge" equilibria), with the implausible implication that any deviation at all from equilibrium would cause the model to diverge farther and farther away from equilibrium. One possible solution, proposed by Nicholas Kaldor (1955–56), was to allow the aggregate propensity to save to adjust by making it depend on the distribution of income between labor and capital. An alternative was to allow substitution between labor and capital, as Solow and Paul Samuelson (1953; Samuelson and Solow 1956) did for multisector growth models, and as Harold Pilvin (1953) did for a one-commodity model (see Ahmad 1991, 87–90).¹² By making production coefficients variable, Solow and Samuelson (1953) resolved

9. However, in an editorial comment at the end of their facsimile reprint of Solow 1956, Stiglitz and Uzawa (1969, 87) correct errors and typos in equations on pages 84, 85, 86, 87, 90.

10. Swan (1956) draws attention to real-world complexities such as the role of technical progress when there are diminishing returns because of a fixed supply of land or the interaction between investment and technical progress. Swan's concern that growth models do not capture enough of reality to provide direct prescriptions for growth is shown by his introduction to Swan 1964: "In this paper I intend to ask more questions than I can answer, and mainly to urge that economists need to consider very closely what it is that theories of economic growth are about, what questions they are trying to answer, if economic theory is not merely jejune mathematics."

11. Pitchford (2002, 383) mentions that prior to the seminar, Swan was reading Robinson 1956.

12. Ahmad (1990, 112 n. 20) reports, "In a recent personal communication, Professor Solow agrees that Pilvin's contribution (1953) deserves recognition, but . . . rightly draws our attention to the treatment of the non-steady-state path in his model (1956). The main difference is that Solow traces the path of capital intensity in the non-steady state, Pilvin the path of income." Solow (1956, 83) cites John Chipman's published comment on Pilvin 1953, but gives no indication of having read Pilvin 1953.

the problem that, with fixed coefficients, the multisector growth model of John von Neumann (1945–46) was overdetermined. Thus the original contribution of Solow (1956) and Swan (1956) was not the elimination of the Harrod-Domar knife-edge by making the output-capital and capital-labor ratios endogenous, because that had been done by Pilvin (1953) and Solow and Samuelson (1953). Rather, Solow and Swan created a simple, convenient, and powerful apparatus for finding the steady-state growth path of a one-commodity world. In addition, Swan demonstrates the importance of technical progress for long-run growth. Technical progress is considered by Solow, but Solow's fundamental contribution is not until Solow 1957.¹³

Rather than addressing the knife-edge problem, Swan 1956 could be viewed as trying to sort out the differences between classical and neoclassical approaches to growth. Swan considers the role of technical progress in a classical setting in which there are diminishing returns because of a fixed supply of a third factor, land. A main question is the rate of technical progress that is necessary to prevent population pressure from moving the economy to a Malthusian outcome. A higher savings rate (and a faster accumulation of capital) raises the growth rates at every point, but only temporarily interrupts the inevitable progress toward the stationary state determined by technical progress and the rate of growth of the labor supply. In the words of Solow (1997, 596),

Swan notices that the model makes technical progress a powerful way of improving the standard of living and capital accumulation a disconcertingly weak reed. He looks for an answer to “this anti-accumulation, pro-technology line of argument” and mentions two possibilities. One is very classical: if higher output per head will induce faster growth of the labor force, then something like Arthur Lewis's unlimited supply of labor is present, and additional capital accumulation becomes much more powerful. His second idea is that “the rate of technical progress may not be independent of the rate of accumulation of capital, or . . . accumulation may give rise to external economies, so that the true social yield of capital is greater than any ‘plausible’ figure based on common private experience. This point would have appealed to Adam Smith, but it will not be pursued here.” Of course that point is now being pursued by an army of economists.

13. Swan (1956) and Solow (1956) both assume “neutral” technical progress, but an error prevents Solow from showing that the capital-output ratio is constant in equilibrium (see Dixon 2003).

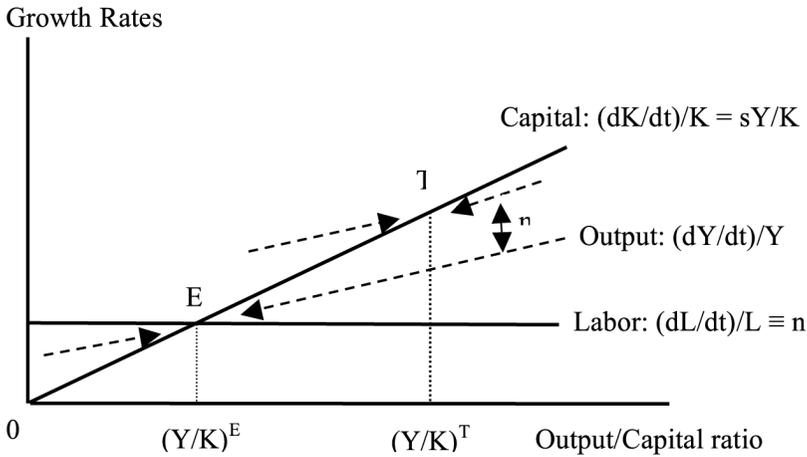


Figure 1 The Swan diagram

3. The Swan Diagram

At a fundamental level the growth models of Solow 1956 and Swan 1956 are the same. A main difference is expository: Solow’s diagrams focus on the capital-labor ratio, whereas Swan’s diagrams focus on the output-capital ratio and rates of growth. Figure 1 illustrates the basic Swan diagram with the output-capital ratio (denoted Y/K) on the horizontal axis and growth rates on the vertical axis.

In the simplest version of Swan 1956, the growth rate of labor, shown as $(dL/dt)/L \equiv n$ in figure 1, is exogenous and hence is represented by a horizontal line.¹⁴ Since investment is equal to savings and saving is a fixed proportion, s , of income, it follows that $dK/dt = sY$. The rate of growth of capital, shown as $(dK/dt)/K = sY/K$ in figure 1, is simply a straight line through the origin with slope s . With constant returns to scale and no technical progress, the rate of growth of output, $(dY/dt)/Y$, is intermediate between (or equal to) the rates of growth of capital and labor as shown by the lower-level dotted arrows in figure 1.¹⁵ Equilibrium is at E , where the

14. Swan later relaxes this assumption to consider the response of labor supply to changes in income.

15. For a Cobb-Douglas production function, $Y = K^\alpha L^\beta$ with $\alpha + \beta = 1$, Swan (1956) obtains $(dY/dt)/Y = \alpha sY/K + \beta n$. For a linearly homogeneous production function used by Swan (2002) in postseminar notes the equation is the same except that α and β are no longer constant (see Pitchford 2002, 385).

rates of growth of capital, labor, and output coincide. Anywhere to the left of point E , output is growing faster than capital, so Y/K rises toward $(Y/K)^E$. Anywhere to the right of E , output is growing more slowly than capital, so Y/K falls.

Exogenous technical progress at rate m shifts up the growth rate of output by m , leading to a new equilibrium at T in figure 1 with a higher output-capital ratio, $(Y/K)^T$. While Solow's diagram highlights the substitution between labor and capital, Dixon (2003) points out that the Swan diagram has the advantage of directly showing the effects of technical progress. For any given rate of technical progress, Y/K is constant in equilibrium, whereas the K/L ratio used by Solow needs to be redefined in efficiency units for it to remain constant.

4. Why the Solow Diagram Rather Than the Swan Diagram?

Any look at recent textbooks will show that the economics profession eventually adopted Solow's 1956 diagram for analyzing steady-state growth (for a given technology) in terms of the capital-labor ratio and his 1957 growth accounting equation (with technical progress measured as the "Solow residual"), rather than Swan's 1956 diagram. Why? Solow (2007, 3) cites "a collection of reasons of different kinds, none individually of very great importance."

The first reason cited by Solow is that "Swan worked entirely with the Cobb-Douglas function; but this was one of those cases where a more general assumption turned out to be simpler and more transparent" (3). Solow (1997, 596) also remarks that

[Swan's] model works exclusively in Cobb-Douglas terms (mostly with constant returns to scale). This allows an exposition entirely in terms of growth rates. Although this formulation fits in well with the literature of the time, it obscures the general-equilibrium character of the model. Between them, the limited generality and the preoccupation with growth rates may account for the fact that Swan's mode of exposition did not catch on.

Swan's December 1956 *Economic Record* article did indeed use the convenient Cobb-Douglas production function (used decades before Charles Cobb and Paul Douglas by Knut Wicksell and familiar to Swan from Wicksell 1934, 1:274–99, a book he much admired). Solow (1956,

1957) based his main analysis on a general production function, although textbook exercises with the growth accounting equation of Solow 1957 often use Cobb-Douglas, the student's friend. But Swan's analysis was based on a general, constant returns to scale (linearly homogeneous) production function in his 1956 presentation of his growth model at the previously mentioned ANU seminar and in his 23 July 1956 postseminar notes. Pitchford (2002, 383) recalls that during the seminar, "Conrad Leser . . . made the suggestion that Swan should consider using the Cobb/Douglas production function to exposit his model."¹⁶ Also, Geoffrey Sawer, a professor of law and then director of ANU's Research School of Social Sciences, commented that Swan's diagram would be clearer with percentage rates of growth instead of units of output on the vertical axis. The eventual publication of Swan's postseminar notes as Swan 2002 was much too late to alter the widespread identification of Swan's analysis with a specific functional form.

Swan was also involved in developing the constant elasticity of substitution production function, of which Cobb-Douglas (elasticity of substitution equal to one) and Leontief fixed-coefficients technology (zero elasticity of substitution) are special cases. Arrow et al. (1961, 143n) remark in a footnote, "We note that Trevor Swan has independently deduced the constant elasticity of substitution property of [their equation 11, the CES production function]. The function itself was used by Solow (1956, p. 77) as an illustration." They (Arrow et al. 1961, 154) also observe that Swan's doctoral student, Pitchford (1960),¹⁷ "considers the introduction of a CES production function into a macroeconomic model of economic growth and concludes that at least in some cases this amendment restores to the saving rate some influence on the ultimate rate of growth." However, the literature generally overlooks these mentions of Swan and Pitchford (and of Solow 1956, 77), so that, for example, Ahmad (1991, 24) refers to "the general form of the constant elasticity of substitution production function, originally examined in some detail by Arrow, et al. (1961)."

16. Leser was an economist working at the Canberra University College, which in 1960 became the School of General Studies within the ANU.

17. Other Australian contributions to capital and growth theory in the wake of Swan 1956 include Pitchford and Hagger (1958) on the conditions for uniqueness of the internal rate of return and Warren Hogan (1958), who corrected a calculation error in Solow 1957. W. E. G. Salter (1959, 1960) published on embodied technical change and vintage capital, but this work arose from a 1955 Cambridge PhD dissertation predating Swan 1956 (see Swan's 1963 obituary of Salter).

Swan published his papers after long reflection, if at all: “Economic Control in a Dependent Economy” was presented in a seminar, “Social Control,” on 30 June 1953 but not published until March 1960. His best-known paper outside growth theory, “Longer Run Problems of the Balance of Payments” (Swan [1963] 1968), was mimeographed and circulated in May 1955, eight years before publication. His 1945 paper, “The Principle of Effective Demand,” appeared posthumously as Swan 1989. So until 2002 it appeared incorrectly (thanks to Swan’s acceptance of Leser’s suggestion about simplicity of exposition), that Swan’s 1956 analysis of steady-stage growth was, unlike Solow’s analysis, limited to the Cobb-Douglas functional form (notwithstanding the footnote in Arrow et al. 1961 acknowledging Swan’s independent statement of CES).

Barbara Spencer believes that her father’s reluctance to publish was mainly due to an extremely high standard that he set for his own work and to an inherent modesty as to the value of his academic contributions. For example, Swan (1956, 334, 342) claims very little with respect to the paper’s contribution to the literature: “The aim of this paper is to illustrate with two diagrams a theme common to Adam Smith, Mill, and Lewis, the theory of which is perhaps best seen in Ricardo,” and “the model used above differs from Harrod’s model of economic growth only in that it systematizes the relations between the ‘warranted’ and ‘natural’ rates of growth, and introduces land as a fixed factor.” In deciding on the contribution of economic analysis (whether theory or econometric estimation), Swan placed a huge weight on the importance of the work for economic policy in addition to requirements for originality and rigor. Swan 1964, “Growth Models: Of Golden Ages and Production Functions,” prepared for the roundtable conference (1960) in Japan,¹⁸ explains some of the inadequacies of growth models for practical development. It is also likely that Swan’s interest in further contributions to the growth literature was reduced by the frustrations of dealing with bureaucracy while working on India’s five-year plan in 1958.¹⁹

According to Solow (2007, 4): “A second and more substantial reason (for the adoption of Solow’s approach) was that Swan saw himself as responding to Joan Robinson’s complaints and strictures about capital and growth, while I was thinking more about finding a way to avoid the

18. We thank Aiko Ikeo for pointing out that the International Economic Association’s roundtable conference held at Gamagori (near Nagoya) in April 1960 was the first international conference in economics held in Japan.

19. For the difficulties that Swan faced in India, see Rosen 1985.

implausibilities of the Harrod-Domar story.” Some indication that Swan 1956 was regarded that way is provided by Geoffrey Harcourt in his introduction to Harcourt and Laing 1971, where he refers to the “model which Swan used in the famous article (1956) which preceded his even more famous appendix, the latter being designed to keep off ‘the index number birds and Joan Robinson herself’” (12).²⁰ Only the appendix, “Notes on Capital,” was reprinted in Harcourt and Laing 1971, not the main part of the article, placing Swan’s appendix squarely in the context of the Cambridge capital controversies (on which, see Bliss, Cohen, and Harcourt 2005).

Swan’s appendix defended those who, like Swan and Solow, used aggregate capital and an aggregate production function in their growth theorizing, against the criticism of Robinson (1954, 1956). Such a defense was the motivation for the appendix, not the motivation for the growth theory itself. There is only a brief mention of Robinson and the capital-theoretic issues she raised in Swan’s (2002, 376) postseminar notes, which was the preliminary version of the main body of Swan 1956. Swan’s growth model was certainly read by many separately from his appendix. For example, as pointed out by a referee, Mordecai Kurz (1963) extended Swan’s growth model to a two-sector framework, and W. Max Corden (1971) based his extension of the neoclassical growth model to an open economy on the Swan diagram.

Solow (1955–56) also replied to Robinson in an article that attracted sufficient notice to be reprinted by Stiglitz and Uzawa 1969, with the opening salvo, “Mrs. Robinson was annoyed at many of the practices of academic economists. We have reason to be grateful for her annoyance, for she seems to have written her article [Robinson 1953–54] in the way that an oyster makes pearls—out of sheer irritation.” The oyster making pearls out of sheer irritation is an image as striking and memorable as the scarecrow keeping away the index-number birds. To the extent that Swan 1956 lost attention as the Cambridge capital controversies lost the profession’s interest, why did the same not apply to Solow 1956? Swan tacked on his response to Robinson as an appendix to his growth model, while Solow published his response separately as a comment in the same journal in which Robinson (1953–54) had appeared, the *Review of Economic Studies*.

20. Swan’s appendix (1956, 343) opens with the following, “If we had to put up a scarecrow (as Joan Robinson calls it) to keep off the index-number birds and Joan Robinson herself, it would look something like this.”

The difference is as much an accident as Swan's acceptance of Leser's suggestion of using a Cobb-Douglas production function for a more accessible exposition, but such accidents can matter in how a contribution is received by the profession.

Solow (2007, 4) suggested, "A third reason is that Swan was an Australian writing in the *Economic Record*, and I was an American writing in the *Quarterly Journal of Economics*." As a matter of course (and perhaps of patriotism), Swan published all his papers in Australia, and all but one (a 1986 book review) in the *Economic Record*—indeed, it was "known that Dick Downing (the then editor of the *Economic Record*) was supposed to be holding an issue of the *Economic Record* in anticipation of publishing Swan's [growth] model" (Pitchford 2002, 386). Swan 1956 was reprinted several times in North America (in Newman 1968, Williams and Hufnagle 1969, Stiglitz and Uzawa 1969), and in the years following its publication Swan was invited to visit MIT, Yale, and Cambridge. His work did not face any language barrier of the sort that delayed the discovery by anglophone economists that Maurice Allais (1947) had published the overlapping-generations model of money eleven years before Samuelson, the square-root rule for the transactions demand for money before Baumol and Tobin, and the golden rule of capital accumulation fifteen years before Edmund Phelps. Even so, economists, like other academics, can be parochial, and impact depends on place of publication. International communication was slower then: journals traveled to Australia by sea mail, with the February 1956 issue of the *Quarterly Journal of Economics* arriving at Canberra in April. Still, Canberra was not that isolated: indeed, as previously mentioned, Swan's seminar presentation in 1956 was attended by no less a luminary than James Meade.

5. Conclusion: Neoclassical Growth in the Antipodes

Trevor Swan (1956, 2002) independently developed the standard neoclassical growth model. Swan 1956 was published ten months after Solow 1956 but included a more complete analysis of technical progress, which Solow treated separately in Solow 1957. Solow's 1956 diagram highlights the substitution between labor and capital. By relating the output-capital ratio to rates of growth, Swan's diagram is able to directly illustrate the effects of variations in the rate of technical progress. But Swan's article was ultimately overshadowed by Solow's, partly because Solow's article

appeared first, but also because of accidental factors. Comments by Leser on Swan's 1956 seminar presentation led Swan to adopt an exposition in terms of the Cobb-Douglas production function, even though his original version (not published until 2002) had a general functional form. Solow (1955–56) published his response to Robinson 1953–54 separately, as a comment in the same journal that had published Robinson's article, while Swan appended his response to Robinson to his article on the neoclassical growth model. Consequently, Swan 1956, but not Solow 1956, may have been perceived as an episode in the Cambridge capital controversies, of which the economics profession grew tired. The infrequency of Swan's subsequent publication also cost him attention and left him out of the later expansion of the literature on growth theory: Swan 1964 demonstrated that steady-state growth requires technical change to be Harrod-neutral, but his Fisher Lecture at Yale in 1962–63 and his Marshall Lecture at Cambridge in 1963 were not published and do not even survive among his papers. Information about his Giblin Lecture, "Structure and Stress," delivered to the Australian and New Zealand Association for the Advancement of Science (ANZAAS) in 1967 is limited to three pages of shorthand notes. Of his 1977 presidential address, "Population Growth and Economic Development" to section G of ANZAAS, all that exists in his papers are two pages of notes taken by Heinz Arndt. These factors let Swan 1956 be overshadowed, so that his mode of exposition did not catch on, but that cannot detract from the remarkable achievement that Solow (1997, 594) describes as "Swan's independent version of the standard neoclassical growth model."

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