CHAPTER
Invention, Innovation, Investment: Heterodox Simulation Modeling of Technological Capital Accumulation[1]

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The Three INVs – Invention, Innovation and Investment

'Innovation' is the application of accumulated technological and organisational knowledge in a new form ('invention') to increase the set of techniques and products commercially available in the economy. For the purposes of this chapter, innovation will refer to technological knowledge only. As a process over historical time, technological innovation has been analysed with strong empirical evidence by Mensch (1979) to indicate it plays a crucial role in the long-run dynamics of modern capitalism. Twenty years later, Cantwell (1999) provides a strong endorsement for this role of innovation from a wide range of studies since 1979. Classical economics recognised that innovation embodied in the form of new machines through fixed capital 'investment' is the essential process for realising economic development (see Cantwell, 1999, p. 226). Adam Smith (1937) identified this innovation process in terms of division of labour and specialisation, and then applied it to his pin factory example. From the beginnings of the Industrial Revolution, the dynamics between invention, technological innovation and their manifestation in the form of fixed investment have been identified as sources of cyclical growth, structural change and development.

Mainstream economics virtually ignores the roles of invention and process innovation in investment research, except as exogenous forces. The central neoclassical literature on investment behaviour is based on the seminal work of Dixit and Pindyck (1994), where uncertainty is handled as calculable (or probabilistic) risk and capital stock is homogeneous. At the aggregate level, the endogeneity of technical change in the new neoclassical growth model has left the linkage highly tenuous. Hossian and Chung (1999, p. 1081), when they discuss innovation in evaluating neoclassical growth theory, identify "… the inadequacy of the one-factor stochastic growth models in describing the dynamic behaviour of (real) macroeconomic variables". Joan Robinson and the post-Keynesians of the 1960s 'Cambridge Controversies in the Theory of Capital' would have agreed.

All heterodox economists share a strong appreciation of dynamic behaviour in economic development and therefore place significant emphasis on the roles of invention, innovation and investment. However, two problems arise. One is the inevitable major variations between the different schools of heterodox economics on their approaches to these dynamic forces, but the second is more fundamental. This is the inability of any school on its own to provide a *complete behavioural explanation* of the tripartite 'INV process': from invention to innovation to investment. Post-Keynesians concentrate on investment, neo-Austrians on invention and entrepreneurship, and evolutionary Schumpeterians on innovation. What is required is a modeling exercise that unites all three heterodox approaches into a unified behavioural process in the same way that classical economists first introduced innovation into their analysis of the Industrial Revolution.

The aim of this chapter is to provide a model that incorporates the three-stage INV process in a coherent dynamic behavioural context using essential insights from post-Keynesian, neo-Austrian and evolutionary economic thought. A deterministic, causal, nonlinear and dynamic 'complex economic systems' model is developed to track the growth and cyclical development of a simple corn-credit economy over 100 years of simulated historical time. The model has a post-Keynesian base centred on John Maynard Keynes's aggregate demand, Michał Kalecki's income distribution macroeconomics and Joan Robinson's recursive investment-profit relationship. The Schumpeterian macroeconomic environment is embedded into the model, so that innovation is planned within the context of the business cycle and the long-run evolving nature of innovation. The next step is to include a neo-Austrian mechanism that allows choice of techniques (having varying gestation periods) to determine the types of process innovation that are introduced into this corn-credit economy. A profit-maximising algorithm is included to govern the choice of techniques, in a way that provides an appreciation of the productivity implications, as have been examined by Wilfred Salter (1960). This model represents an inclusive heterodox approach to the INV process, which is employed through computer simulation experiments to produce results that are analysed for an appreciation of the type of traverses that emerge and their policy conclusions.

The next section of the chapter provides an outline of the heterodox framework that is embedded in the model. The first of the ensuing three sections lays out the nonlinear dynamic model of a simple corn-credit economy using only *circulating* capital and explains the computer simulation methodology. The model is extended to include *fixed* capital and its behavioural specifications are identified, after which some simulation results are presented. Analysis of these results, limitations, and conclusions that arise make up the final three sections.

Heterodox Approach to Inquiry

The core of this approach is that investment, stimulated by *expected* profitability and financed by loans, drives the economy through short-period business cycles while accumulating capital for long-period economic growth. The outcome of such cyclical growth is the *realised* profitability that emerges, providing both the rationale and the wherewithal for the next round of investment decisions and their financing. Michał Kalecki established the fundamentals of this core in many of his writings, where the two-way nature of the investment-profitability relationship impacts on the pattern of the business cycle (Courvisanos, 1996)[2]. Robinson (1956) extended this relationship by recognising Keynes's psychological factors in the 'animal spirits' of entrepreneurs when making investment decisions. This occurs through expectations of profitability impacting on the extent of investment spending. As expectations alter through the business cycle (in the light of realised results), this affects the aggregate demand being stimulated by investment and thus it impacts back on the business cycle. All this occurs endogenously, with time lags that make the cyclical patterns irregular, but recurring.

The last formulation of his capitalist investment model in Kalecki (1968) attempts to integrate business cycles with economic growth. An important element of this integration is the effect of technical progress on investment through innovation. Innovation is what introduces technical progress (invention) into the capital accumulation process, allowing the new investment to capture a higher profit rate due to the enhanced productivity of labour. This path implies process innovation. Kalecki (1968) also mentions "technical novelties" which enable entrepreneurs to "do better than the average" (Osiatyński, 1991, p. 442). This path hints at product innovation.

However, Kalecki's attempt to incorporate innovation into the capital accumulation process is simplistic and ambiguous. There is no clear distinction between product and process innovation; also, the terms 'invention' and 'innovation' are used interchangeably, without any clear appreciation of the separate processes and different economic implications. Finally, the innovation variable in Kalecki's investment function is labelled as 'semi-autonomous', implying some endogenous element; but with no clearly identified human agency or internal business process, Kalecki ends up falling back on the standard exogenous treatment of innovation.

From a Kaleckian perspective, Steindl (1976, p. 133) identifies research and development spending [R&D] as the mechanism by which innovation becomes endogenous to the investment process, accompanying the process of investment "like a shadow". Gomulka (1990, pp. 45-7) goes further by seeing invention *via* R&D as central to the endogenous innovation process, with large firms earning strong profits having the ability to activate large R&D budgets. The macrodynamics of the evolutionary approach provides the most appropriate examination of innovation as an endogenous process that can dovetail into the Kalecki-Robinson base analysis.

The classic evolutionary proposition comes from Schumpeter (1939), where the investment function responds to waves of optimism and pessimism to create *clusters* of innovation, which then are diffused through the *bunching* of investment: the ‘clust-bun’ effect. This leads to investment cycle patterns and the development of a trigger mechanism to significantly increase the rate of investment in endogenous (incremental) innovation on the basis of a specific exogenous basic (or radical) innovation. At the bottom of the investment cycle a trigger to initiate a ‘virtuous circle’ effect occurs with investment rising to diffuse basic innovation. This increases the amplitude of the expansion phase of the investment cycle, raising innovation intensity and shifting the trend path of economic growth upward.[3] An opposing ‘vicious circle’ effect works to reduce innovation intensity, thus sending the investment cycle into a significant contractionary phase.

Schumpeter’s virtuous ‘clust-bun’ effect requires effective demand stimulus through widespread diffusion of the clustering phenomenon that can only be achieved through the availability of profits for investment, or through public sector funding. At this point, the Kaleckian investment analysis explains how the trigger mechanism works.[4] Impediments to this ‘clust-bun’ effect reside in the institutional frameworks of nations (national innovation systems, NIS), particularly the ones with still-dominant mature industries utilising older technologies (Freeman and Perez, 1988, pp. 58-65). Increased uncertainty arising from large investment in the new technology systems also adds an impediment through increased macroeconomic volatility, which Toivanen *et al.* (1999) empirically identify as slowing down the diffusion process. R&D (and technology transfer thereof) provides firms with the potential means to overcome these impediments and set up a more innovative NIS, with profits determining the volume of R&D that firms can undertake. However, a trigger has to set off the application of R&D as innovative activity.[5] By including this approach in a heterodox analysis, the human agency element to the dynamic process of innovation in investment can be incorporated in our suite of simulation models.

Neo-Austrians see the entrepreneur as being alert to opportunities for taking advantage of discrepancies and gaps in the market system.[6] Exploiting opportunities in a rational planning manner adds to the value of the final product by the techniques that are 'put to use'. The more capital-intensive the process of production, the more capital goods are put to use through increasingly complex techniques and the higher market price that the product can command. Value is thus added by the 'degree of roundaboutness' (Canterbery, 1995, p. 264), leading to capital deepening in the economy. The appropriation of monopoly power in the market is evidence of creative and successful entrepreneurship. Such monopoly power is not seen as permanent by neo-Austrians unless such power is underwritten, subsidised and otherwise supported by governments and their regulatory agencies. The heterodox approach adopted in this inquiry accepts this 'put to use' technique choice as the *objective* value in neo-Austrian analysis, without necessarily accepting any *subjective* corollary of the optimum social outcome from such a technique choice.[7]

The final theoretical component required in the heterodox analysis for this chapter, is an extension of the neo-Austrian choice of techniques scenario. The simulation models will set out four techniques. One is the basic use of crude, hand-fashioned implements (costless to the capitalist farmer) for planting, cultivating, harvesting and threshing the corn. Then, through R&D expenditures, three more-elaborate techniques are developed. Their implementation is a complex entrepreneurial decision. Not only does the entrepreneur need to consider the degree of roundaboutness of each vintage of capital stock, but also the extent of coexisting vintages in the production process. This second decision uses Salter (1960) as the insightful means of determining what proportion of the entrepreneur's labour force should be equipped with each available known technique.

A profit-maximising [*R-max*] algorithm allows the entrepreneur to determine, at the margin, the labour force proportions they need to equip with each available known technique. Salter (1960), from a neoclassical perspective, recognises a variety of techniques and the prices associated with different capital goods, then applies his own *R-max* algorithm to arrive at a combination of new techniques and 'fossils' of past techniques still in operation. From this mechanism, Salter (1960, p.57) shows that "…the replacement decision is both a scrapping decision and an investment decision."

Process innovation in Salter's precise decision-making routine is the vehicle by which technical change is incorporated into capital accumulation and thus enables the higher potential productivity of new ideas and inventions to be realised as higher levels of actual productivity. Salter (1960, p. 69) concludes, "…higher operating costs is the price paid for retaining outmoded method." With this Salter routine, Harcourt (1966) argues for rejection of the standard neoclassical CES-type production function and instead for using the process of substitution for current 'best practice' techniques in economic analyses. This type of investment decision-making is consistent with the Kaleckian investment model and provides further support for the bunching of investment around 'best practice' techniques identified earlier.

This completes our exposition of the heterodox approach that will be adapted for the computer simulation models constructed in the next three sections. In summary, this inclusive approach identifies a dynamic process of investment decision-making that drives the business cycle, structural change and long-term economic growth. Investment spending affects the cycle through the aggregate demand mechanism, while the impact of investment decisions on choice of techniques determines the extent of innovation and its impact on economic growth and development.

The expansionary phase of the business cycle induces R&D and increases invention activity. Adoption of these potential new techniques (and products) will occur during the subsequent downswing in the business cycle, when increased unemployment allows for more start-up entrepreneurs (Audretsch and Acs, 1994) and 'mothballing' of old capital stock allows for clustering of innovations (Silverberg and Verspagen, 2003). With Kalecki's gestation period for investment to establish multiplier effects, more highly productive techniques and the truncation of investment in old capital stock, the business cycle begins its new expansionary phase, and the innovations in operation shift the cycle's trend upwards for faster economic growth. Most of these heterodox aspects are incorporated in the corn-credit economy models of circulating and fixed capital discussed in the next two sections.

The Circulating Capital Model of a Corn-Credit Economy

In this section, a dynamic, nonlinear and recursive *circulating capital* model based on Richardson (2002, 2004) is constructed, which we first solve for its stationary state, then use to generate a steady state of growth, before initiating an endogenous business cycle; one whose peaks and troughs recur over 100 years of simulated historical time. This pure capitalist 'corn-credit economy' is a synthesis of theoretical insights gleaned chiefly from the writings of William Petty, David Ricardo, Knut Wicksell, Michal Kalecki, John Maynard Keynes, Joan Robinson, Gunnar Myrdal and Basil Moore.

The action takes place on a vast alluvial plain, with constant favourable weather conditions. Each capitalist 'yeoman farmer' family owns a tract of inherited land having constant uniform fertility and utilises inherited buildings which, properly maintained, never depreciate. The richest farmers also act as bankers, extending their trusted credits (at the market rate of interest) to their fellow farmers, accepting deposits and splitting the interest proceeds between themselves and all bank depositors on a per annum [pa] basis.

The bulk of the population comprises a mobile workforce of fieldhands who negotiate money wage rates with the farmers and, together with their families, reside on their (most recent) employer's farm at zero cost. Labour productivity also is uniform and constant, so employment depends upon the size of crop sown/harvested and on this productivity coefficient. The harvest is determined by the quantity of seedcorn planted, which itself is a function of expected profitability – as affected by farmers' views about the corn price, wage rate and interest rate. There are no pure landlords because, in Ricardian/Marshallian terminology, there is neither an intensive nor an extensive 'margin of cultivation' likely to give rise to ground rent. Rather, the level region's cultivated area will contract and expand as the economy's investment-driven production and employment cycles ebb, flow and propagate.

The structural form of the Corn-Credit simulation model is a system of nine equations, 14 identities, nine behavioural and technical constants, and finally, five initial conditions as at the base period (Year 0). The full model is set out in the Appendix. In this model, four equations (B, E, F, G) and four identities (2, 3, 11, 12) need clarification:

(B) Seedcorn Invested

At the end of Year t, capitalist farmers hold *static expectations* that the Profit Rate they just realised (r_t % pa) also will feature in their corn trading accounts after the annual harvest (and 52nd weekly market) of Year t+1, so that re_{t+1} % pa = r_t % pa. This assumption of *static, naïve* or *myopic* expectations is adopted for analytical clarity and justifies the presence of r_t on the RHS of equation (B). Also enclosed within the square brackets is n_t, the normal profit rate of identity (6), a.k.a. the required rate of return, opportunity cost of capital and hurdle rate of return. Subtracting this second rate from the first defines the Profitability Gap which, when multiplied by the behavioural Reaction Coefficient (ϕ), sets the percentage by which farmers (on average) determine this year's quantity of Seedcorn Invested (Qi_t sacks pa) shall *change* relative to the previous end-of-year volume (Qi_{t-1} sacks pa). With *circulating* capital consumption being total, lagged Seedcorn Investment (once Year t rolls round) may be likened to a stock of *fixed* capital that undergoes a 100% pa rate of depreciation during the same year it enters into the economy's annual corn production function.

(E) Corn Price

This equation originates in the economic growth and income distribution models of Robinson (1956) and Harcourt (1963). At the series of weekly markets held during Year t, all stored Foodcorn Supplied (Qs_{t-1} sacks) is sold to the workers, bankers and depositors in exchange for all the money wages (W_t dollars pa) and interest payments (J_t dollars pa) they earn – assuming no dollar saving out of these functional income categories. As a matter of logic, the farmers *must* receive back as the overall average corn price (P_t dollars/sack) *all* of their current wage and interest outlays in return for *most* of their previous year's crop, i.e. that part of Q_{t-1} sacks of corn not retained by them for investment purposes (Qi_{t-1} sacks) and for their own consumption (Qf_{t-1} sacks).

(F) Money Wage

At the start of Year t, each farmer negotiates with potential employees over whether the money wage ruling in Year t-1 should be increased/maintained/decreased. Both sides realise that Labour's bargaining position is weakened (and Capital's strengthened) if the coming year's unemployment rate ($[e_t -1]$%) will be 'high' and if the previous year's corn price inflation (gp_{t-1} % pa) was 'slow'. In this case, the money wage (w_t dollars/fieldhand pa) will fall below its former level. Other combinations are possible, but the interesting question is how Labour and Capital know about the current year's unemployment rate before it is recorded. This occurs because both sides will have observed how much seedcorn was placed in the barns at the end of Year t-1, hence are able to calculate how much Employment will be offered (relative to the known Workforce) to raise the crop during Year t.

(G) Interest Rate

In Year t, each banker is assumed to perceive an increase (decrease) in the lender's risk he is bearing whenever the Debt:Equity Ratio of identity (12) has grown (declined) relative to its level in Year t-1 for the individual farmer seeking an overdraft to finance his share of the economy's Wage Bill, defined as identity (1). So, if the D:E Ratio Growth Rate (gd_t % pa) is positive/zero/negative, the banker will raise/maintain/lower the Interest Rate previously negotiated for that particular farmer. The individual:aggregate relationship is handled by an 'average of individual behaviours' [AIB] assumption, under which all technical and behavioural parameters are merely economy-wide 'measures of central tendency', surrounded by distributions of individual parameter values. AIB is the same implicit assumption that economists use to horizontally sum individual demand functions into a single 'market demand function'. Each consumer in the market has a different set of demand elasticities, so 'the' own-price, cross-price and income elasticities governing total consumption of (say) corn must represent an average of individual behaviours (AIB).

(2) Seedcorn Capital

Farmers rule off their books after each harvest is home and each year's 52nd and final weekly foodcorn market has been held. Only at the end of Year t are they in a position to compute what rate of profit they realised, because only then do they observe what average Corn Price was received. This (now-known) *price* (P_t dollars/sack) is the opportunity cost of Qi_{t-1} sacks pa, the previous year's (long-known) *volume* of Seedcorn Invested – which they alternatively *could* have sold as foodcorn early this year but instead chose to have it sown. Multiplying these two figures yields Seedcorn Capital for Year t.

(3) Foodcorn Capital

The Year t Corn Price is what actually was received, on average, for all the Foodcorn Supplied that previously had been placed in the granaries at the end of Year t-1. This stock progressively was run down as the weekly foodcorn markets were held to dispose of it to consumers. On average throughout Year t, therefore, *one-half* (since $\kappa = 2$) of Qs_{t-1} sacks of lagged Foodcorn Supplied was on hand in the farmers' granaries as their stock-in-trade.

(11) Average Debt

Fieldhands are paid fortnightly the money wages they need to shop for victuals at the weekly foodcorn markets. When the capitalist farmers who employ them approach the capitalist bankers with their schedules of *fortnightly overdrafts* (to meet these weekly payrolls), the borrowers wish to minimise their interest payments. They therefore negotiate schedules of *weekly repayments*, since money from foodcorn sales is known to flow in on a weekly basis. Throughout Year t, therefore, the farmers' Average Debt to the bankers will be one week of their annual payroll, i.e. their Wage Bill divided by $\mu = 52$.

(12) Debt:Equity Ratio

At the start of Year t, the bankers will know the farmers' Average Debt, but their Capital Stock value will not be available until the Corn Price is computed at the end of Year t. The best available measure of d_t, therefore, is D_t dollars divided by the Year t-1 Capital Stock (also in dollars) minus D_t. The risk-averse bankers need this information so they can calculate the farmers' Debt:Equity Ratio (and its D:E Ratio Growth Rate), then alter the Interest Rate they charged during the previous year, if necessary.

Figure 1 presents the structural-form equations of the Circulating Capital corn-credit economy in the shape of a flowchart, so that the interactions that take place in this system of mutual (*not* simultaneous) determination can be more easily appreciated. In particular, the flowchart shows how no less than *five* 'arrows of causality' are aimed at the Realised Profit (R_t) dollars pa. This is because, unlike the stable 'contractual incomes' of wages and interest, the economy's stream of R_t earnings is classed as a 'residual income'. This name correctly implies that the information-rich R_t aggregate is the economy's most sensitive variable. R_t represents the combined net effect of any and every alteration in all other prices, quantities, costs and incomes within this recursive dynamic system.

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With the growth rate set at g = 0 (stationary state), the 'Mathematica' computer program is used to eliminate all identities before using the 'Excel' and 'Solver' programs to code, solve and experiment with the corn-credit model. The resulting reduced form is shown in Table 1 below, with nothing on the right-hand side of its equations but the *known* values of the model's parameters and predetermined variables.

Reduced-form equations show how all unknown quantities are determined by other quantities whose values are *known*. This is in contrast with structural-form equations, which do have unknown quantities on their right-hand sides. In brief, structural forms define the *behaviour* of economic agents and the technologies they utilise, while reduced forms display the underlying economic *mechanisms* which the structure implies.

This reduced form contains four key equations, for Seedcorn Invested (Qi), for the Realised Profit Rate (R_t), for the Corn Price (P_t) and for the Interest Rate (i_t). Three of these equations are long, complex and difficult to interpret. As in all corn models, the short, simple and easy to interpret Realised Profit Rate equation turns out to have *physical corn* in both its numerator (flow of profit) and denominator (stock of circulating capital).

Lagged Seedcorn Invested (Qio) appears on the right-hand sides of all seven reduced-form equations. Therefore, all seven endogenous variables (Q, Qi, L, r, P, w, and i) are being driven through simulated historical time by the sequence of previous-year values for Qi. The fact that Qio^2 helps drive seedcorn invested, the corn price and the interest rate indicates a degree of complexity characterising the model's cyclical behaviour.

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The central driving force of Qio is amplified or moderated by the presence of other lagged variables, e.g. Qso (Foodcorn Supplied) appears on the RHS of three equations. The Money Wage determinants (wo and gpo) appear in four equations and the determinants of the Interest Rate (io, do and Ko) in three.

Recall that Qi (hence the time-series of Qio) is itself driven by the sequence of [r – n] profitability gaps – themselves dependent on Qio as per equations (D') and (G') above. This (as well as the flowchart in Figure 1) will give some indication of the high degree of circular and cumulative causation inherent in the corn-credit model.

The structural-form equations and identities have to be coded (using ‘Excel’, in this case) and the model solved. This is done by first setting g = 0, so that successful achievement of a stationary state (with all time-series plots ‘flatlining’) represents an equilibrium solution. There are n = 7 unknown variables to be determined but only n – 1 = 6 independent equations available to do this because one structural-form relation is *not* independent. Equation (D) is a mere identity, the definition of the realised profit rate: $r_t = [R_t / K_t]$% pa. Therefore, the corn-credit model is under-determined, having one too many unknowns than independent equations to determine its solution. This situation of under-determination is quite common in theoretical economics.[8]

In this case, the corn-credit model is made just-determined by reducing *its* number of unknowns. The procedure is complicated by the equation system being mutual, dynamic and recursive (historical time), rather than merely simultaneous (logical time) as with the neo-classical system. In principle, one simply sets the profitability gap to zero by forcing $r_t = n_t$, then solve the model. But to *enforce* this stationary-state condition for 100 simulated crop years, the experimenter needs to follow a certain procedure commonly used for numerical analysis. One must apply the powerful ‘hill-climbing’ search algorithm Solver, which keeps on making small alterations to one or more parameters until the realised profit rate (r_t % pa) comes into strict equality with the normal profit rate (n_t % pa) during each and every year of the century of simulated historical time.

This dynamic solution procedure guarantees a stationary state that must persist, because every one of the 100 annual profitability gaps has been reduced to zero by the Solver algorithm. In other words, the farmers' profitability expectations for next year are always being realised and, in addition, their opportunity cost of capital is always being covered.

With the help of Solver, a set of initial conditions and constants (as listed above) was identified. It turns out that the most important constant is the investing farmers' Reaction Coefficient ($\phi = 0.4818$) for achieving a stationary state of long-period equilibrium between r_t % pa and n_t % pa for t = 1, 2, 3, …, 100. In this situation, the farmers experience no surprises or dissatisfaction and so they are content to keep on investing $Qi_t = 40{,}000$ sacks of seedcorn once each crop has been harvested.

Figure 2 is a time-series plot of the 'flatlining' of several endogenous variables, indicating that long-period stationary-state equilibrium has been attained. In fact, *all* endogenous variables fail to grow or cycle in the stationary state, but analogies with intensive-care patient monitors are wide of the mark. In fact, a corn-credit economy in stationary-state equilibrium will continue to sustain its people at their customary standard of living for an indefinite period … provided there also is zero population growth, which is true of Figure 2 as attested by the flatlining of the Workforce ($N_t = 16{,}000$ fieldhands).

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Figure 3 shows what happens when the Growth Rate is set at g = 0.01, so that both the Workforce and the volume of Farmcorn increase at the exponential rate of 1% pa.

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Naturally, one also must have raised the Reaction Coefficient (to $\phi = 0.5962$, in this case) in order to give an incentive – in the form of a positive Profitability Gap – to the investing farmers. In fact, this z = [r – n]% pa difference must be around 1.7% pa to make the farmers increase their volume of Seedcorn Invested by g = 1% pa, thus matching the growth rate of the Workforce and the Farmcorn that they themselves consume. The corn-credit economy has attained a 'fully-adjusted' state of full-employment growth with zero wage and price inflation: a "Golden Age", as Joan Robinson (1956) famously called it.

The Reaction Coefficient is like an index of the 'animal spirits' of capitalists. Clearly, those 'Goldilocks' entrepreneurs active in the economy portrayed by Figure 3 got their ϕ = 0.5962 'just right' (for the exogenous Workforce/Farmcorn growth rate) and ushered in a Golden Age.

Figure 4 shows how reducing the Reaction Coefficient below its critical value of 0.5962 drags the corn-credit economy down to ever-lower growth rates until, at $\phi = 0$, the economy flatlines – despite its ever-growing Workforce. The associated spreadsheets show that the annual volume of Foodcorn Supplied per Workforce Member remains at its opening level of 7.2 sacks/fieldhand during the Golden Age, but progressively falls to only 2.5 sacks/fieldhand by Year 100 of this hunger-haunted Stationary State.

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Figure 5 shows what happens to Seedcorn Invested with Phi *above* its critical value.

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The Golden Age growth rate of g = 1% pa is the model economy's Harrodian "warranted rate of growth" and any departure from $\phi = 0.5962$ (below or above) spells trouble, though not in the monotonic increasing fashion that Roy Harrod (1948) expected.

Real-world economies operate in various 'cyclical states', there being powerful endogenous (not merely exogenous) forces that preclude them from being locked into continuing stationary or steady states of growth. This being the *milieu* within which Invention, Innovation and Investment occurs, we have set the corn-credit model's Reaction Coefficient to $\phi \approx 0.62$ to 0.63 in the analyses of Intangible and Fixed Capital which follow.

Adding Fixed Capital to the Corn-Credit Model

In this section, we add vintages of *fixed capital equipment* derived from an accumulation of technological knowledge of three progressively more advanced 'outfits' or 'toolkits' of implements for raising the productivity of fieldhands undertaking various duties: planting, cultivating, harvesting, threshing. Each of these three new ‘techniques’ (or ‘vintages of fixed capital equipment’) first must be **Invented**. Later they will be **Innovated** and fixed capital will have to be **Invested**.

R&D budgets are authorised, and ‘inventors’ hired at the going annual wage rate of $200, because farmers continually strive to exploit, and if possible enlarge, profitability gaps between the known costs of, and the higher expected returns on, their capital stocks. This extension of our pure capitalist corn-credit economy is a synthesis of theoretical insights gleaned chiefly from the writings of Joseph Schumpeter, John Hicks, G.L.S. Shackle, G.B. Richardson, Richard Nelson, Paul David and Donald Lamberton.

In the Circulating Capital model of the previous section, there is no stock of fixed capital helping determine average labour productivity (α) of 10 sacks/fieldhand pa. In that primitive economy, one perhaps can imagine the fieldhands knapping flints into harvesting blades and gathering tree limbs for shaping and fire-hardening into seed-dibbers, digging sticks and threshing-flails. The point is that all this happens *outside* working hours, so that the real costs are borne by the workers and their families. So initially, our capitalist farmers are not sinking *any* dollars into the discovery (Invention), the first commercial application (Innovation) and, eventually, the routine hiring of artisans (Investment) to manufacture higher-productivity – but also more complex and higher-cost – outfits of fixed capital equipment for helping their fieldhands produce more corn with fewer labour hours.

The history of scientific and technological development lends weight to a key assumption: the *Laws of Nature* are such that 'out there' lies a long series ('The Sequence') of such improved techniques of production just waiting to be discovered – given sufficient 'inventor manyears' allocated to pure and applied R&D. (This assumption does no violence to the post-Keynesian axiom of a Non-Ergodic Universe, since it is the inevitable outcome of later inventions combining existing knowledge with new insights.) Table 2 shows the situation before even *one* entrepreneurial farmer has hired some former fieldhands to be 'inventors' (R&D expenditure), let alone 'artisans' (Fixed Investment).

R&D expenditure is required to activate the first INV, Invention. Table 2 shows how many Inventor Manyears are needed to bring forth the first three inventions in The Sequence: 40 for vintage B, 100 for vintage C and 680 for vintage D. History also suggests there is a definite *order* in which scientific and technological discoveries are made, e.g. television *could not* appear until after radio had been invented. A society mired in the labour-only technique A cannot leapfrog intervening stages by, say, locking 680 inventors in a compound then waiting for them to emerge with technique D in one year's time. The inventors first deliver B and then C, but there will have been insufficient manhours for them to invent vintage D. The knowledge they gain from B is *the* prerequisite for discovering C, etc. and *knowledge accumulates* over time, which is why our 40, 140 and 820 Cumulative Inventor Manyears are the correct 'trigger points' for inventions to appear in their right vintage order.

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In early capitalist societies like this corn-credit economy, the commitment of R&D funds to hire Inventors is a luxury akin to gambling: farmers will only do it if they can *afford to lose* all their stake money. We cannot view capitalists' decisions to risk their money on the *first* INV as the result of rational calculations like those underlying their adoption of techniques that already exist. In our Fixed Capital Model, therefore, a positive Critical Profitability Gap of z* = 2.0% pa is arbitrarily specified. All profit earned in excess of this figure is devoted to hiring inventors at the going money wage rate. This is done in the *hope* (because nobody really knows The Sequence) that a new technique will be discovered, one having a productivity payoff in excess of its capital cost. This is our explanation for why inventions tend to occur in the vicinity of cyclical peaks, since that is the time when the farmers' *realised profitability* is at its highest. At all the three cyclical peaks in the 100 simulated years of historical time, the profitability gaps are *above* the 2.0% pa Critical Profitability Gap that trigger the authorisation of R&D budgets to hire inventors.

As each succeeding year opens, capitalist farmers review their usage of all fixed capital vintages invented thus far. Their resulting decisions (based, as always, on attempting to widen their current profitability gaps) determine the Innovation and Investment components of our three-stage endogenous INV process. This extension, which relies on standard profit-maximisation behaviour, completes our Fixed Capital Model.

Table 3 shows the situation if all three inventions had been made, but farmers had no financial incentive to adopt any of these new techniques. Note that the stocks of outfits and employment of fieldhands equipped with these toolkits are all set to zero.

PLACE TABLE 3 HERE

Despite holding opposing views on the role of the public sector, both neo-Austrians and post-Keynesians recognise the presence of pervasive disequilibria and view the economy as a thoroughly dynamic construct, which grows and develops through historical time via capitalist entrepreneurs identifying and exploiting the highest expected-profitability opportunities available to them.

Table 3 also displays what neo-Austrian economists would recognise as the increasing 'roundaboutness' of more capital-intensive techniques, which involves making ever more complex and longer gestation-period investments in means of production. In other words, the table shows a 'lengthening' – from 12 through 24 months – of the Austrian 'period of production', the time that elapses between the first input of 'original factors' (labour and land) and the consequent and subsequent first output of 'final commodities' (corn).

For concreteness, suppose these outfits (one is needed per fieldhand) are built around the (B) Trowel/Knife, (C) Hoe/Sickle and (D) Spade/Scythe combinations of wood-hafted metal tools – the accompanying seed-drills, corn-threshers, bird-scarers, etc. also rising in number and complexity with each new technological 'vintage'.

The increasing metal content of these implements alone could explain why gestation periods lengthen. Each artisan must find, mine and crush the ores; smelt, refine and forge the metals; then shape and fit the wooden handles, completing one outfit in 1, 1.5 or 2 years, depending on vintage. The artisans are paid the same money wage as when they worked as fieldhands; like inventors, artisans welcome being assigned to lighter and more interesting duties. This means that each toolkit in the economy's stock of outfits has a capital cost of w_t dollars (type B), $1.5w_t$ dollars (type C) or $2w_t$ dollars (type D) to the farmers who authorise these investment projects. For simplicity, we assume the service life of each outfit to be the same, regardless of vintage, so that a common declining-balance depreciation rate of fixed capital equipment applies, e.g. $\delta = 10\%$ pa.

However, aptitude for the artisanal trades is not distributed uniformly throughout human populations and farmers are likely to have to pay for the supervision of those less able. So, instead of Lm = 10 artisans being required to make their first 10 toolkits, farmers may need to hire (say) Lm = 10 + (0.00092 x 100) = 10.092 artisan manyears because some supervision of those having less aptitude is needed. More generally, if farmers calculate that ΔB or ΔC or ΔD outfits are the profit-maximising numbers to order built during some particular year, they will have to employ: $Lmb = \Delta B + \sigma\, \Delta B^2$ or $Lmc = \Delta C + \sigma\, \Delta C^2$ or $Lmd = \Delta D + \sigma\, \Delta D^2$ artisans, respectively, where $\sigma = 0.00092$ is the Artisan Aptitude coefficient.

In the fixed capital corn-credit economy, the former A- or α- or a-technique (with fieldhands organising their own planting, cultivating, harvesting and threshing methods) will gradually be replaced by these newly-invented, more productive technologies.

In any given year, average fieldhand productivity (afp) will depend on the mix of technologies in use. Suppose afp = α = 10 sacks per fieldhand pa because the current 'mix' of techniques is simply the old A-technology, but then a newly-invented B-technique guarantees a higher fieldhand productivity of β = 12 sacks per fieldhand pa. (For the sake of this example, we ignore Table 3, which shows that actually β = 10.04 and not 12.) A capitalist farmer planning to harvest (say) 1,200 sacks pa clearly would *like* to equip 100 of his usual 120 A-fieldhands with the new B-technology and sack the rest, thereby cutting 20.w dollars from his annual wage bill. However, the farmer will need to invest in fixed capital, i.e. pay a team of artisans to manufacture outfits of the new planting/cultivating/harvesting/threshing B-implements to equip some portion of his workforce. Yet it is not likely to be *financially viable* to equip a full five-sixths (or 100 fieldhands) of his customary 120-strong A-workforce with the new B-technology all at once.

Unlike circulating capital (created simply by holding back corn from last year's harvest), the fixed capital created during Year 0 must be financed with bank loans, serviced with interest payments and depreciated over 10 years. Annually, during Years 1 through 10, depreciation allowances held back from gross profits will end up in the hands of bankers, as farmers use them to pay back the loans they raised to employ artisans during Year 0 only.

It takes one year (all of Year 0) for one artisan to build one of the new B-outfits and each fieldhand must be equipped with one B-toolkit in order to produce his 12 sacks of corn annually over the next 10 years. Artisans (Lm) and B-fieldhands (Lb) are paid the same wage rate as the existing A-fieldhands (La), i.e. w = \$200 pa. Total employment during Year 0 will be L = Lm + La workers pa. But during each of years 1 through 10, total employment will be Lf = La + Lb fieldhands. The Y-outfits depreciate (and the bank loans are repaid) at the rate of $\delta = 10\%$ pa while in service during Years 1 through 10.

Capitalist farmers will need to apply some kind of profit-maximisation (or *R-max*) algorithm to decide what proportion of their existing A-workforce should be equipped with the newly-invented B-vintage during the coming year.[9] The farmers' *total* employment of fieldhands will depend on the answer, of course, because the existing mix of technologies has a certain average labour productivity (afp = α) and the new technique has a productivity of $\beta > \alpha$. Note that the crop size (Q_t sacks pa) is already fixed by the economy's opening stock of seedcorn (Qi_{t-1} sacks), which has a known yield of θ sacks per sack of seedcorn planted.

Farmers, therefore, perform a *gendanken-experiment*. They think: With static expectations, how many B-toolkits should I order built during Year 0, while maintaining financial viability? I'd earn the same R_0 dollars of profit annually over the following 10 years if I stick with the old A-technology. But, at the margin, there must exist some profit-maximising or optimal number of B-toolkits for me to build and introduce into the mix.

Farmers must repeat this notional calculation annually, i.e. each time what then (in t-1) was *next* year becomes what now (in t) is *this* year, economic conditions no doubt will have changed. Then our farmers will *reset* their static expectations (in light of the simulation model's latest realised results) and perform their same notional calculation for the new Year 0 and the new Years 1 through 10 … but using the fresh economic data, of course.

The farmers' objective, therefore, should be to annually maximise their Present Value of Expected Profits (PVR), which is a function of Lb, *inter alia*. The stock of B-outfits at the start of Year 0 is zero and, c*eteris paribus*, the stock during each of the next 10 years will be ΔB. This means that ΔB = Lm = Lb represents how many B-toolkits (also artisans in Year 0 and B-fieldhands from Year 1 onwards) will be required.

If the objective function is 'hill-shaped' when PVR is plotted against Lb, then setting its first derivative dPVR/dLb = 0 will reveal the optimal number of B-equipped fieldhands (Lb) the farmer should employ during Years 1 through 10. Hence, the optimal flow of B-toolkits (ΔB) to build, and the optimal number of artisans (Lm) to hire in Year 0. To check that Lb defines a 'hill-top' – rather than a 'valley-floor' – we need to make sure that the PVR function's second derivative $d^2PVR/dLb^2 < 0$.

Ignoring time subscripts, the Expected Profit identity for the notional 10 years is

$Re = Y - Wf - Ka - J - i.(1 - \delta^t).Kf - \delta^t.Kf$ dollars pa,

where:

$Y = P.Q$ = value of harvest in dollars pa

$Wf = w.Lf$ = fieldhand wage bill in dollars pa

$Lf = La + Lb$ fieldhands

$Ka = P.Qio$ = value of seedcorn in \$

$J = i.D = i.Wf/\mu = i.w.(La + Lb)/\mu$ = interest on fieldhand wage bill in dollars pa

$i.(1 - \delta^t).Kf$ = interest charge on loan in dollars pa

$\delta^t.Kf$ = depreciation charge (loan repayment) in dollars pa

$Kf = w.\Delta B$ (toolkits) $= w.Lm$ (artisans) $= w.Lb$ (fieldhands) = cost of fixed capital in \$

Note that there is no profit element in fixed capital equipment because each farmer hires artisans to build up his own stock of B-toolkits.

Neither Y nor Ka vary with Lb, so expanding only those terms which *do* vary with Lb, the Expected Profit identity becomes:

$Re = Y - w.(La + Lb) - Ka - i.w.(La + Lb)/\mu - i.(1-\delta)^t.w.Lb - \delta^t.w.Lb$ dollars pa

There are two terms in the interest rate (i% pa). The *first* is the interest cost of having to borrow the fieldhand wage bill fortnightly, while paying it back after each weekly foodcorn market, meaning that $\mu = 52$. The *second* is the interest cost of having to take out a loan to cover the artisan wage bill during Year 0, with repayments spread over 10 years so that the outstanding balance declines at $\delta = 10\%$ pa … and the interest payments along with it.

Also, there are two terms in (La + Lb) = Lf, the total employment of fieldhands. Luckily, Lf is a direct function of Lb, because every extra five B-fieldhands substitute for one A-fieldhand. So, we start with the number of A-fieldhands needed to produce the fixed annual crop of Q sacks, La = Q / α. Substitution of B-fieldhands occurs because they are more productive (β = 12 sacks pa) than the existing A-fieldhands (afp = α = 10 sacks pa). Every time an extra B-fieldhand is added to the Lf mix, he displaces

(β – α)/α = (12 – 10)/10 = 2/10 = 1/5 = 0.2 or one-fifth of an A-fieldhand.

Thus, for varying numbers of B-fieldhands, the total wage bill w.Lf or w.(La + Lb) will be w.[Q/α – Lb.(β – α)/α], which we now substitute into the Expected Profit identity as:

Re = Y – w.[Q/α – Lb.(β – α)/α] – Ka – i.w.[Q/α – Lb.(β – α)/α]/μ – i.(1–δ)^t.w.Lb – δ^t.w.Lb dollars pa.

In the farmer's present value calculation (over a notional 10-year time horizon), for any given value of Lb it is only the final depreciation cost term and the second of two interest cost terms which vary with time (t = 1, 2, …, T) and therefore change his Expected Profit.

The Present Value of Expected Profit equation is

$$PVR := \sum_{t=1}^{10} \frac{\left[Y - w\cdot\left[\frac{Q - Lb\cdot(\beta-\alpha)}{\alpha}\right] - Ka - i\cdot w\cdot\frac{\left[\frac{Q - Lb\cdot(\beta-\alpha)}{\alpha}\right]}{\mu} - i\cdot(1-\delta)^t\cdot w\cdot\left(Lb + \sigma\cdot Lb^2\right) - \delta^t\cdot w\cdot\left(Lb + \sigma\cdot Lb^2\right)\right]}{(1+i)^t}$$

The first derivative of PVR with respect to Lb is

$$\frac{dPVR}{dLb} = \sum_{t=1}^{10}\left[\left(\frac{A(1+i/\mu)}{(1+i)^t}\right) - B(1+2\sigma Lb)\right]$$

By setting this derivative equal to zero, the optimal value of Lb is found to be

$$Lb = \sum_{t=1}^{10} \left[\left(\frac{A(1+i/\mu)}{iw(1-\delta)^t + \delta^t w} - 1 \middle/ 2\sigma \right) \right]$$

where $A = \dfrac{w(\beta - \alpha)}{\alpha}$

Finally, the second derivative is

$$\frac{d^2 PVR}{dLb^2} = \sum_{t=1}^{10} (-2\sigma B)$$

where $B = \dfrac{iw(1-\delta)^t + \delta^t w}{(1+i)^t}$

and its value clearly is negative, because of the –2 numerical constant.

Excel Workbooks containing the spreadsheets and charts of all three corn-credit models are available from the authors. In the Fixed Capital Model, the Reaction Coefficient used to generate the cyclical state of growth is set lower than in our Circulating Capital Model, i.e. $\phi = 0.6202$ instead of 0.6302. This minor decrease in the 'animal spirits' of entrepreneurs ensures that the disruptions inevitably caused by the fixed capital investment needed to introduce three new techniques of production are minimised. However, the first of our three cyclical peaks no longer is of sufficient amplitude to raise the Profitability Gap above its critical value of $z^* = 2\%$ pa, hence no inventors can be hired and discovery of the B-technology must await the second boom. This is a small price to pay because not one, but two new techniques (C and D) now are discovered around the peak of the third cycle. This demonstrates Schumpeter's 'clustering of inventions/innovations', which is followed by a ‘bunching of investments’ as the subsequent cyclical trough is approached: the ‘clust-bun effect’.

Figure 9 shows the flows and their accumulation (the stocks) of technological knowledge (or intangible capital) in the form of Inventor Manyears.

PLACE FIGURE 6 HERE

The calendar years when each of the three techniques is invented are shown in Figure 7.

PLACE FIGURE 7 HERE

To demonstrate the new technology ‘inevitable disruptions’ and their aftermath, the time series of Growth Cycles in Figure 8 have been plotted over two centuries.

PLACE FIGURE 8 HERE

There are three spikes in the annual growth rates, on the downswing phases of the second and third cyles of Realised Profit. These disruptions also show up in the other two variables plotted above. During the second century of simulated historical time, all growth cycles are reducing in amplitude, as the economy settles down to a regime of production using only the D-technology. Figure 8 also shows how the annual growth rate of Realised Profit (gR) peaks around the year there occurs a point of inflection during the upswing in the graph of the Real Investment growth rate (gIr), i.e. when gIr begins to decelerate. As expected, the cycle of Real Gross Product growth rates (gYr) follows the gIr cycle with a lag.

Our Fixed Capital Model provides a Salter-inspired solution to the difficult choice of techniques problem, which neoclassical growth analysts (empirically, not just theoretically) often 'solve' by assuming a perfectly malleable stock of 'real capital' that can be mixed with labour in variable proportions to produce corn, i.e. a production function relating Q_t sacks pa to the (fixed) capital-labour ratio, or real value of fixed capital equipment per fieldhand (x = Kf/Lf) in our terminology. Figure 9 shows how x behaves over simulated historical time, after technique B is invented and innovated.

PLACE FIGURE 9 HERE

The average fieldhand productivity (afp) performance tracks the capital-labour ratio precisely, with its three arcs corresponding to the introduction of techniques B, C, and D. Each year's opening stock of techniques will be δ = 10% smaller than last year's closing stock due to depreciation – unless, of course, this year's investment outlays partially, fully or more than restore these losses due to the Law of Entropy and the one-way Arrow of Time.

The B-artisans have secure employment during the 12-month Investment Projects of their farmers. However, the C- and D-artisans may not see out their 18- or 24-month employment contracts, due to what neo-Austrian economists call Truncation. Next year's *R-max* algorithm runs, made *in the light of realised results*, might indicate to capitalists that it is *no longer optimal* for them to stick with the C or D Investment Project they initiated under *this* year's assumptions. In other words, the farmers' static expectations may prove to have been under-fulfilled, leading them to cancel the building of (some? all?) extra C- and D-vintage outfits, sack the artisans and scrap their work-in-progress. In short, these long-gestation capital projects might be 'truncated', as does occur with the C-artisans in Figure 10 when the D-technique is innovated.

On the other hand, should investor-expectations turn out to be over-fulfilled, neo-Austrians no doubt would agree that this year's Investment Programme will be 'expanded'.

Analysis of Results

The computer simulations we have carried out provide a clarification of how the dynamics of the three-phase INV process in capitalism works itself out at the basic level of a fixed capital corn-credit economy. Results from these computer runs indicate how the process operates as simulated historical time passes. Analysis relating to the first element of the INV process (invention) is performed, before examining how this is linked to the other two (innovation and fixed investment).

Introducing ‘invention’ of new fixed capital vintages into the basic circulating capital model enables one to appreciate the routine that allows these techniques to be made available in the economy. R&D budgets are authorised, and inventors hired, whenever there exist ‘excess profits’ above a certain critical datum. This is called intangible investment (see Webster, 1999) and forms the basis of a future productivity payoff from inventions in more efficient means of production. Excess profits tend to arise and magnify as the business cycle reaches the higher parts of the expansionary phase (boom). The model shows that particularly strong booms can produce enough excess profits to bring forth more than one invention. This clustering of inventions/innovations around peaks is the necessary forerunner to the bunching of innovations/investments around troughs discussed in the literature and reviewed at the beginning of this chapter. Weak booms tend to spawn single inventions, while low-amplitude booms may result in none at all, since there would not be adequate excess profits for R&D expenditure or knowledge enhancement.

Adding ‘investment’ (in fixed capital) opens the way for the first commercial applications (‘innovations’) of a new ‘invention’ to the economy’s system of production. Consistent with the stylised facts and the evolutionary economics literature, investment/innovation can bunch as the business cycle trough is approached. The innovation process amplifies the profitability stimulus that causes the cyclical downswing to reach its turning point and begin its climb into the new expansionary phase. Our 200-year graph (Figure 8) shows that an upturn in realised profits (R_t dollars pa) occurs *before* the lower turning point in corn production (Q_t sacks pa). Thus, in our model, realised profits constitute a ‘leading indicator’ of production, in accordance with the stylised facts of cyclical growth.

In this deterministic model, the take-up of inventions needs to be activated by some routine rooted in the human agency of entrepreneurs. The problem is that capitalists must make a choice, even if there is only *one* new technique (e.g. beta) waiting to be innovated, since the 'backstop' technology of labour-intensive production (the alpha 'vintage') already exists. Hence the choice of techniques, and extent of appropriation of each technique, is made to be determined by a profit-maximisation algorithm.

'Investment' is linked closely to the innovation process. In the computer model, innovation is the first successful attempt at employing artisans to build the fixed capital equipment necessary to introduce a newly-invented process of producing corn more efficiently. This is only the first instance of fixed investment spending. But once innovation has reached critical mass, investment expenditure 'bunches' and reaches such a strong level that it amplifies the coming turning point in the investment cycle and, with a time lag, drives upwards the business cycle. The time taken from the first innovation via investment spending to when investment in this new process innovation is substantial enough to help alter the cycle in the corn-credit economy is called the 'diffusion of innovation'. A long diffusion occurs when the critical mass takes a long time to develop, while a very short diffusion occurs particularly in exogenously stimulated innovation processes when the critical mass builds up very quickly. The critical mass diffusion time is strongly influenced by the national systems of innovation and how they are consolidated through globalisation processes (Cantwell, 1999, pp. 235-9).

The conditions in a real-world economy are much more involved than in our computer-simulated corn-credit economy, which makes the process of diffusion very complex (see Braun, 2003). However, what our model is tracking is the traverse of the INV process in a virtual economy, so that the dynamic elements of these complex processes are understood at a fundamental level. This allows some basis for further research focussing on the innovation component in models that more closely resemble the real world.

Profit-maximisation decides the amount of investment that will be dedicated to each of the available inventions that are in the system. The extent to which investment is dedicated to the new techniques (through innovation) also will determine the fate of the earlier vintage(s). The greater the bunching of investment in the new techniques, the more the economy leaves behind old established capital stock that will not be replaced with new investment. This will help produce a powerful upturn in the business cycle as aggregate demand is stimulated by the bunching of new investment and realised profits rise with improved productivity. If there is relatively little investment in the new vintage(s), the cyclical upturn will be subdued, with lower aggregate demand stimulation and a smaller rise in productivity-induced profits.

The INV process must now be analysed as a whole, binding together all the elements discussed above. Invention is determined by profitability being high enough to allow excess profits to be invested in R&D. As excess profits rise in the boom we see R&D spending increase. This R&D builds up a set of techniques (and associated technological knowledge) that are available for commercialisation. This is the process of innovation that can begin immediately after invention at the top of the boom, but there will be some time lag before the elements of invention log-jam, labour availability, gestation period and critical mass create conditions for a trigger mechanism to set off an innovation-push into large volumes of fixed capital investment. During this period, investment in circulating capital will be falling, and with it other components of aggregate demand, as the economy is enduring its contraction phase. Innovation-push bunching of fixed capital investment will add to the stimulus given to circulating capital investment from the profitability 'leading indicator' and help drive the business cycle back up into an expansion.

Diffusion of innovation(s) by the leading innovative organisations/firms is determined by the time lag from when the first innovation attempt succeeds to when the critical mass of a cluster of innovations helps generate an upturn. The expansion then will snowball into a boom that generates ever-higher excess profits and a new round of R&D spending. This whole INV process sets up the elements for the virtuous circle effect identified in the innovation literature. 'Best practice' techniques would be the observable routines that emerge from this virtuous circle.

Finally, truncation of fixed capital investment can occur when the entrepreneurs' *R-max* algorithm indicates that new investments need to be made in some recently developed technique. This can enhance the virtuous circle effect, though at the cost of temporary unemployment of artisans and scrapping of their work-in-progress.

Limitations of the Model

Two major limitations exist in the corn-credit economy model and the resulting analysis derived from our preliminary computer simulations. The first is the complexity-based recursive nature of this model. The interactions and feedback effects create severe technical problems. Every extra element that is introduced has the potential to 'blow-up' the model through the massive feedback effects occurring through the century of economic activity that is being simulated. Potentially almost endless streams of complications that bring this model closer to reality are possible, but the time factor is always limiting. The authors hope that others will join them in further articulating the basic corn-credit model, in the same way as neoclassical economists are ceaselessly creating extensions of their simple Walrasian general equilibrium kernel.

The second limitation is the paucity of human agency in the model. Apart from the human agency underlying the structural form of the circulating capital version of the model, all decisions in the fixed capital version are made using only two algorithms. The first determines the quantum of realised profit committed to R&D spending as a function of the excess of the profitability gap over some critical value. The other is the *R-max* algorithm that determines the extent of investment in each available technique and how the workforce is to be equipped with various vintages of fixed capital. Both are crucial to the results. This algorithmic behaviour is a very simplistic and crude version of human agency, yet it provides some robust results that enable us to understand the basic fundamental operations of the capitalist system in a recursive dynamic form. Now that we have such a model based on a valid heterodox approach, behavioral elements of the INV process can be included and evaluated from the base perspective of this model, rather than from the standpoint of a static equilibrium neoclassical model that has no validity in the real world except in terms of what some economists would like to imagine free market nirvana might look like.

This model is deterministic in nature. For economists and econometricians who are familiar with only stochastic models, this approach may seem puzzling, or even anti-scientific (despite its widespread use in modeling for all the physical sciences). As an empirical model, this approach enables us to assign stylised facts to the parameters of the computer model that approach reality in the capitalist system. These facts provide the benchmark from which the model operates. This is quite different to stochastic models based on equilibrium assumptions that result in attributing critical meaning and significance to empirical data that have no relationship to economic reality, but only to nirvana as determined by the assumptions of the stochastic model.

As an ongoing work-in-progress, this model can be used to explore the parameter space for more complex and closer-to-reality results. Adding different parameters, varying the existing ones and modeling others as variables enables one to track and observe the operation of the INV process in the context of different realities. Reswitching of techniques, for instance, would be an interesting phenomenon to explore through different parameters and model specifications.

“We’ve Only Just Begun”

In economic research, the precursor to a full multisectoral system is often a simple one-commodity or ‘corn’ model like the one presented in this chapter. This model is based on a heterodox approach, which emphasises that the (largely credit-financed) capital investments of profit-seeking entrepreneurs drive the business cycle, determine economic growth and alter the income distribution. The traverse is the essential output of the model that provides us with a disequilibrium time-path of adjustment in the economy following some dislodgement from an initial fully-adjusted path of stationary, steady or cyclical growth. This simulation model shows that, under certain conditions, the traverses of even such a basic corn-credit economy will converge to a final fully-adjusted state, although it is possible that the model’s inherent complexity may lead to diverging cycles and, eventually, system collapse.

Using this model, we were able to track the traverses of a simple three-phase INV process. Further parametric explorations can provide richer results with even more robust implications for the complex processes that operate within the invention-innovation-investment triad. The heterodox approach to modeling this simulation program allows us to follow through the whole INV process in one interactive recursive operation, rather than limiting ourselves to neoclassical models that concentrate only on one aspect of this INV process at a time.

The neoclassical approach cannot provide the dynamic appreciation of the complete INV process. However, the *R-max* algorithm tool used in this model enables the process to determine the extent of investment in, and usage in production of, the various techniques in existence. This is an optimising operation that is based on maximising *expected* profits along the traverse. In the non-ergodic world in which our model exists, this optimisation process allows us to develop specific traverses that result in various outcomes, none of which imply that *actual* needs to equal, or even tend towards, *expected* profitability. It would be a fluke if expected profits ever turned out to be identical to actual profits, unlike the neoclassical stochastic models where such an expected profit maximising algorithm always ensures that actual profits are maximised.

Despite the embryonic nature of the computer model presented in this chapter, two major inferences can be derived from its operation. One is the further support provided to the 'clust-bun' effect in the innovation-investment space, adding to the historical quantitative support for this effect in Courvisanos and Verspagen (2002). The other is clustering of inventions derived from R&D spending in the boom. This clustering sets up the possible techniques available to the innovation-investment process. Both inferences provide a first step to understanding the dynamics of the complete INV process. The two effects together deliver volatile but pattern-based cyclical effects in GDP which explain the processes of boom and bust, as well as the long-wave structures that underlie the relative strength or weakness of every downswing and upswing. From such understanding emerge policy implications that ensure a more effective managing of public innovation policy and private sector strategic innovation planning. The search for competitive strengths in regional and national economies has made such innovation policy and planning crucial to the development of dynamic sustainable economic systems.

Tension between virtuous and vicious circle effects operates to create uncertainty that leads to patterns of industry and economy-wide development of cumulative expansion (and booms) along with periods of cumulative destruction of means of production, enforced labour idleness and insecurity. What emerges from these tensions indicates the need for a clear policy and planning framework in a dynamic environment. For public policy, the issue is whether the volatility in cycle effects is sustainable and in what direction. If regions, sectors or even nations exhibit strong remorseless vicious circles based on support for 'fossilised' capital values (e.g. old European centres of power), then systemic failure of capitalism ensures that shifting to an innovative creative accumulation can only be done through strategic intervention (e.g. Ireland and Finland). This supports the post-Keynesian perspective for public intervention, but needs to be tempered with an appreciation of complexity underlying the neo-Austrian perspective.

Only preliminary conclusions based on the initial simulations of the corn-credit economy are possible, but they indicate need for further research in dynamic deterministic models with a strong heterodox approach to the basic modeling exercise. From this research, we are convinced that no single non-neoclassical school of thought is adequate to supply a complete appreciation of the complex processes in the invention-innovation-investment space. The computer model outlined in this chapter is but the beginning of developing more specific regional and national based models. These models could identify appropriate stylised facts that are incorporated into the model in order to provide specific planning and policy support and advice that enable more dynamic and sustainable economic outcomes.

Endnotes

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[2] Courvisanos (1996) identifies four variables when examining the various investment models developed by Kalecki: the level and change in profits, capacity utilisation and finance costs (indicated by the gearing ratio). Not all these variables are represented in the corn-credit model of this chapter, as we are concerned to simplify an already complex set of simulation experiments. As profit is the central factor in the investment analysis of Robinson, it seems appropriate to start with a profitability-based model. We intend to include other variables in a later iteration of this model.

[3] See Toivanen *et al.* (1999) for empirical support on this virtuous circle effect.

[4] See Courvisanos and Verspagen (2002) for empirical support on the 'clust-bun' effect.

[5] Using the evolutionary approach, Lima (2000) examines how market structure impacts on innovation activity through market concentration dynamics. Lima shows that both high and low concentration rates produce a lower innovation rate (and accompanying R&D), compared to intermediate concentration rates. The innovation rate determines the extent of innovation diffusion, which impacts back on the market structure so that easy diffusion reduces market concentration and difficult diffusion raises the concentration rate. Thus market structure (like R&D) is an important factor in the innovative capacity of a NIS, but is not a trigger mechanism in business cycle dynamics. This aspect of the evolutionary approach is not included in this chapter because there are no differing market structures in the computer simulations. There is only one commodity traded on a competitive market – corn – in the three models developed below.

[6] Neoclassical economists call such discrepancies and gaps 'disequilibria in the market'. See Kirzner (1973) for a modern-day exposition of neo-Austrian entrepreneurship.

[7] Examples of actions by entrepreneurs in the recession of the early 2000s indicate that optimum social outcomes may not always result (see Clarke *et al*., 2003).

[8] For example, the neo-classical equilibrium model.

[9] The *R-max* optimisation procedure is aimed at maximising *expected* profits. To this end, static expectations are assumed, but other expectations assumptions could be adopted (*e.g.* least squares, adaptive). Unlike the neoclassical approach, we are not optimising realised or actual profits in this model, where (assuming *rational* expectations) actual would always turn out to be equal to expected profits.

References

Audretsch, D.B. and Acs, Z.J. (1994), "Entrepreneurial Activity, Innovation, and Macroeconomic Fluctuations", in Shionaya, Y. and Perlman, M. *Innovation in Technology, Industries and Institutions: Studies in Schumpeterian Perspectives*, Ann Arbor: University of Michigan Press, pp. 173-83.

Braun, P. (2003), ".comUnity: A Study on the Adoption and Diffusion of Internet Technologies in a Regional Tourism Network", Ph.D. dissertation, School of Business, University of Ballarat, Australia.

Canterbery, E.R. (1995), *The Literate Economist*, New York: HarperCollins College.

Cantwell, J. (1999), "Innovation as the principal source of growth in the global economy", Archibugi, D., Howells, J. and Michie, J. (eds), *Innovation Policy in a Global Economy*, Cambridge: Cambridge University Press, pp. 225-41.

Clark, F., Dean, G. and Oliver, K. (2003), C*orporate Collapse: Accounting, Regulatory and Ethical Failure*, Revised Edition, Cambridge: Cambridge University Press.

Courvisanos, J. (1996), *Investment Cycles in Capitalist Economies: A Kaleckian Behavioural Contribution*, Cheltenham: Edward Elgar.

Courvisanos, J. and Verspagen, B. (2002), "Innovation and Investment in Capitalist Economies 1870-2000: Kaleckian Dynamics and Evolutionary Life Cycles", *Investigación Económica*, Volume LXII (242), pp. 33-80.

Dixit, A. and Pindyck, R. (1994), *Investment under Uncertainty*, Princeton: Princeton University Press.

Freeman, C. and Perez, C. (1988), "Structural crises of adjustment, business cycles and investment behaviour", in Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds.) *Technical Change and Economic Theory*, London: Pinter, pp. 38-66.

Gomulka, S. (1990), *The Theory of Technological Change and Economic Growth*, London: Routledge.

Harcourt, G.C. (1963), "A Critique of Mr. Kaldor's Model of Income Distribution and Growth", *Australian Economic Papers*, Volume 1 (1), pp. 20-6.

Harcourt, G.C. (1966), "Biases in Empirical Estimates of the Elasticities of Substitution of C.E.S. Production Functions", *Review of Economic Studies*, Volume XXXIII (3), Number 95, pp. 227-33.

Harrod, R. (1948), *Towards a Dynamic Economics*, London: Macmillan.

Hossian, F. and Chung, P.J. (1999), "Long-run Implications of Neoclassical Growth Models: Empirical Evidence from Australia, New Zealand, South Korea and Taiwan", *Applied Economics*, Volume 31 (9), pp. 1073-82.

Kalecki, M. (1968), "Trend and the Business Cycle", *Economic Journal*, Volume 78 (2), pp. 263-76. Reproduced in Osiatyński (1991), pp. 434-50.

Kirzner, I. (1973), *Competition and Entrepreneurship*, Chicago: University of Chicago Press.

Lima, G.T. (2000), "Market Concentration and Technological Innovation in a Dynamic Model of Growth and Distribution", *Banca Nazionale del Lavoro Quarterly Review*, Number 215, December, pp. 447-75.

Mensch, G. (1979), *Stalemate in Technology*, Cambridge, Mass.: Ballinger.

Osiatyński, J. (1991), *Collected Works of Michał Kalecki, Volume II Capitalism: Economic Dynamics*, Oxford: Clarendon Press.

Richardson, C.L. (2002), *The Traverses of a Post-Keynesian Model of a Corn-Credit Economy*, Unpublished Ph.D. dissertation, School of Economics, University of Tasmania, Hobart, Australia.

Richardson, C.L. (2004), "The Corn-Credit Economy", paper presented to the Scottish Economic Society Conference, March, Perth, Scotland.

Robinson, J. (1956), *The Accumulation of Capital*, London: Macmillan.

Salter, W.E.G. (1960), *Productivity and Technical Change*, Cambridge: Cambridge University Press.

Schumpeter, J. (1939), *Business Cycles; A Theoretical, Historical and Statistical Analysis of the Capitalist Process*, 2 Volumes, New York: McGraw-Hill.

Silverberg, G. and B. Verspagen (2003), 'Breaking the waves: a poisson regression approach to Schumpeterian clustering of basic innovations', *Cambridge Journal of Economics*, Volume 27, pp. 671-93.

Smith, A. (1937), *An Inquiry into the Nature and Causes of the Wealth of Nations*, New York: Modern Library (originally published 1776).

Steindl, J. (1976), *Maturity and Stagnation in American Capitalism*, Second edition, New York: Monthly Review Press.

Toivanen, O., Stoneman, P and Diederen, P. (1999) "Uncertainty, Macroeconomic Volatility and Investment in New Technology", in Driver, C. and Temple, P. (eds)

Investment, Growth and Employment: Perspectives for Policy, London and New York: Routledge.

Webster, E. (1999), *Economics of Intangible Investment*, Cheltenham: Edward Elgar.

Appendix: The Corn-Credit Economy Model

The full computer model of the Corn-Credit economy is set out below. Note that 'pa' refers throughout to "per annum".

The structural form of the model is a system of nine *equations* for the mutual determination of key quantities and prices, together with the realised rate of profit:

Corn Produced	$Q_t = \theta\, Qi_{t-1}$	sacks pa	(A)
Seedcorn Invested	$Qi_t = (1 + \phi\, [r_t - n_t])\, Qi_{t-1}$	sacks pa	(B)
Employment	$L_t = Q_t / \alpha$	fieldhands	(C)
Realised Profit Rate	$r_t = R_t / K_t$	percent pa	(D)
Corn Price	$P_t = (W_t + J_t) / Qs_{t-1}$	\$/sack	(E)
Money Wage	$w_t = w_{t-1} + \varepsilon\, (e_t - 1) + \rho\, gp_{t-1}$	\$/fieldhand pa	(F)
Interest Rate	$i_t = i_{t-1} + \lambda\, gd_t$	percent pa	(G)
Workforce	$N_t = (1 + g)\, N_{t-1}$	fieldhands	(H)
Farmcorn	$Qf_t = (1 + g)\, Qf_{t-1}$	sacks pa	(I)

To interpret the right-hand sides of these equations we need the 14 *identities* defined below:

Wage Bill	$W_t = w_t\, L_t$	dollars pa	(1)
Seedcorn Capital	$Ka_t = P_t\, Qi_{t-1}$	dollars	(2)
Foodcorn Capital	$Kb_t = P_t\, Qs_{t-1} / \kappa$	dollars	(3)
Capital Stock	$K_t = Ka_t + Kb_t$	dollars	(4)
Realised Profit	$R_t = P_t\, Q_t - W_t - Ka_t - J_t$	dollars pa	(5)
Normal Profit Rate	$n_t = i_t + \varphi$	percent pa	(6)
Foodcorn Supplied	$Qs_t = Q_t - Qi_t - Qf_t$	sacks pa	(7)

Price Level	$p_t = P_t / P_0$	ratio	(8)
Inflation Rate	$gp_t = (p_t / p_{t-1}) - 1$	percent pa	(9)
Employment Rate	$e_t = L_t / N_t$	ratio	(10)
Average Debt	$D_t = W_t / \mu$	dollars	(11)
Debt:Equity Ratio	$d_t = D_t / (K_{t-1} - D_t)$	ratio	(12)
D:E Ratio Growth Rate	$gd_t = (d_t / d_{t-1}) - 1$	percent pa	(13)
Interest Bill	$J_t = i_t D_t$	dollars pa	(14)

To set up the numerical analysis, we need to assign values to the nine behavioural and technical *constants* of the structural form:

Reaction Coefficient	$\phi = 0.4818$ (0.5962) [0.6302] for stationary (steady) [cyclical] growth	
Seedcorn Yield	$\theta = 4$	sacks/sack of seedcorn
Labour Productivity	$\alpha = 10$	sacks/fieldhand pa
Risk Premium	$\varphi = 0.01$	i.e. 1% pa nominal
Foodcorn Capital Turnover	$\kappa = 2$	times pa
Wage Bill Turnover	$\mu = 52$	times pa
Employment Wage Coefficient	$\varepsilon = 4$	ratio
Inflation Wage Coefficient	$\rho = 12$	ratio
D:E Ratio Growth Coefficient	$\lambda = 0.1$	ratio

Finally, only five *initial conditions* need be specified in the base period (Year 0) to begin the passage of this corn-credit economy through 100 ‘crop years’ of simulated historical time:

Seedcorn Invested	$Qi_0 = 40{,}000$	sacks pa
Farmcorn	$Qf_0 = 4{,}878$	sacks pa
Workforce	$N_0 = 16{,}000$	fieldhands
Wage Rate	$w_0 = 200$	dollars/fieldhand pa
Interest Rate	$i_0 = 0.04$	i.e. 4% pa nominal

FIGURES

Figure 1 – Flowchart of the Corn-Credit Model

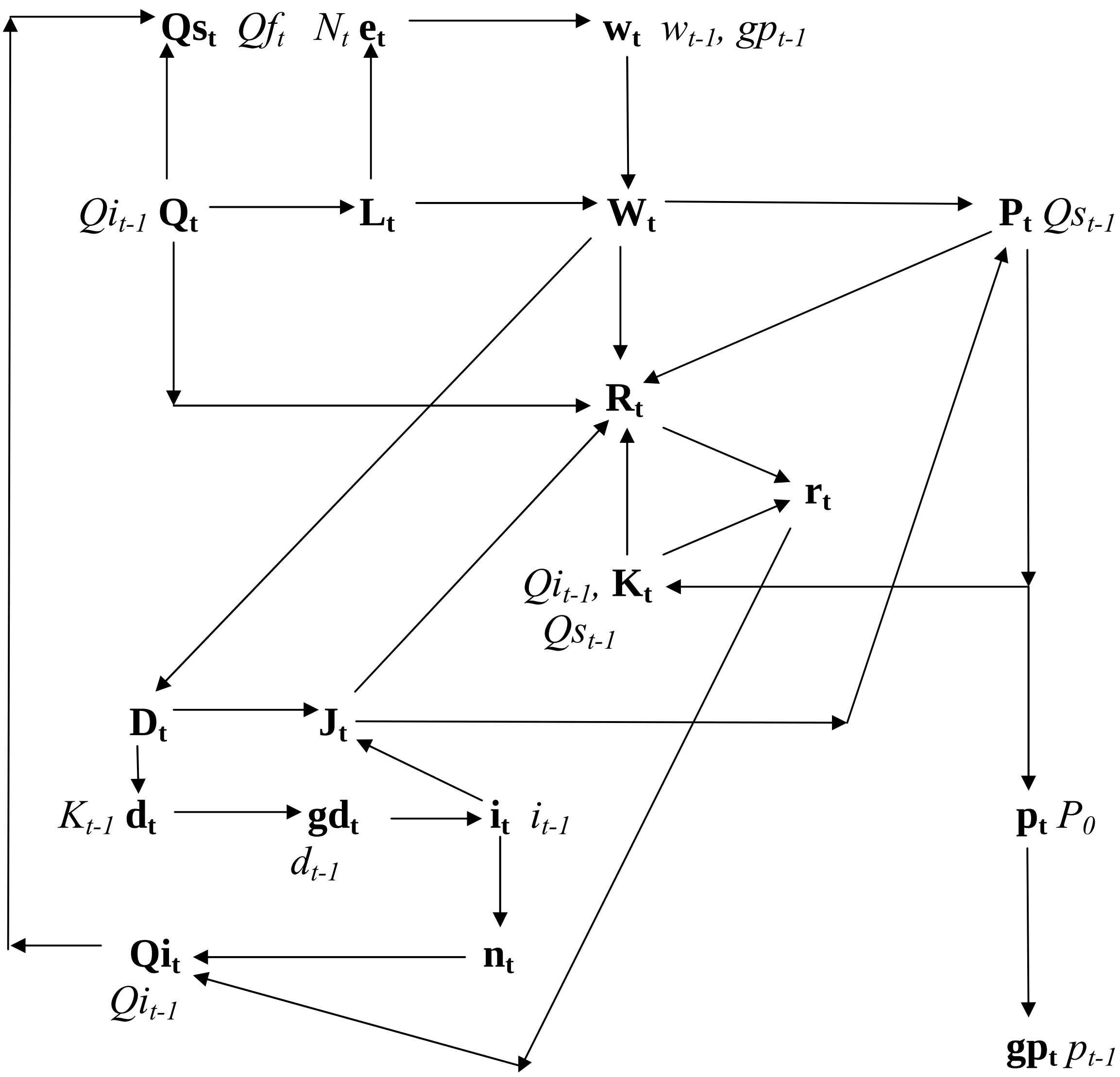
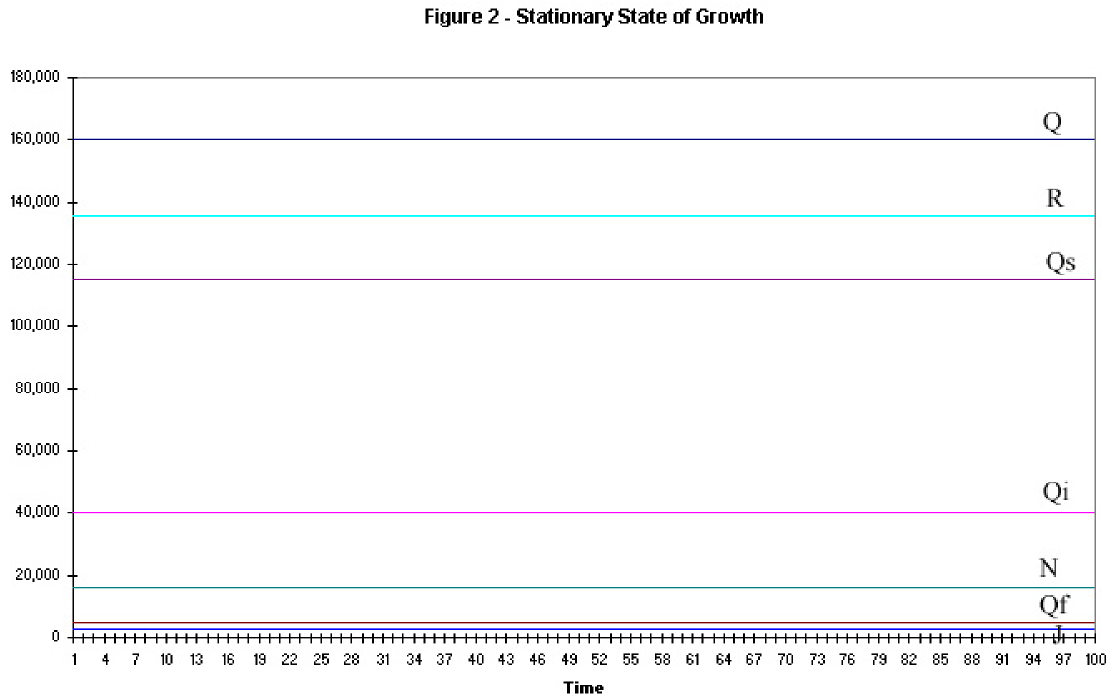
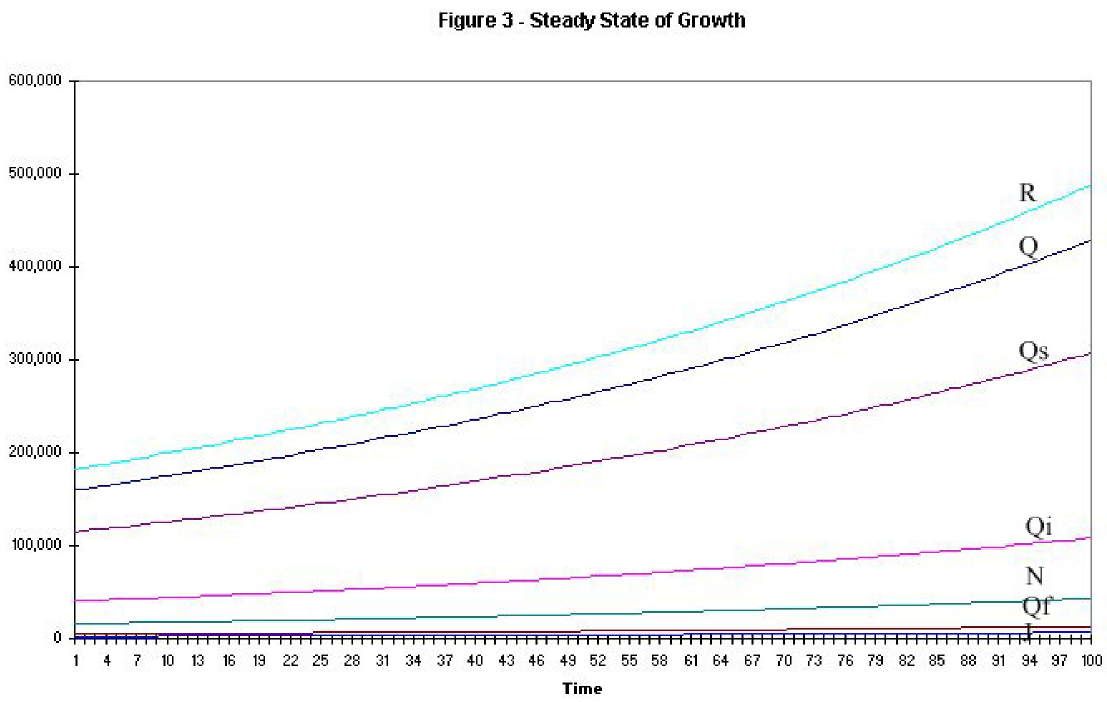


FIGURE 2



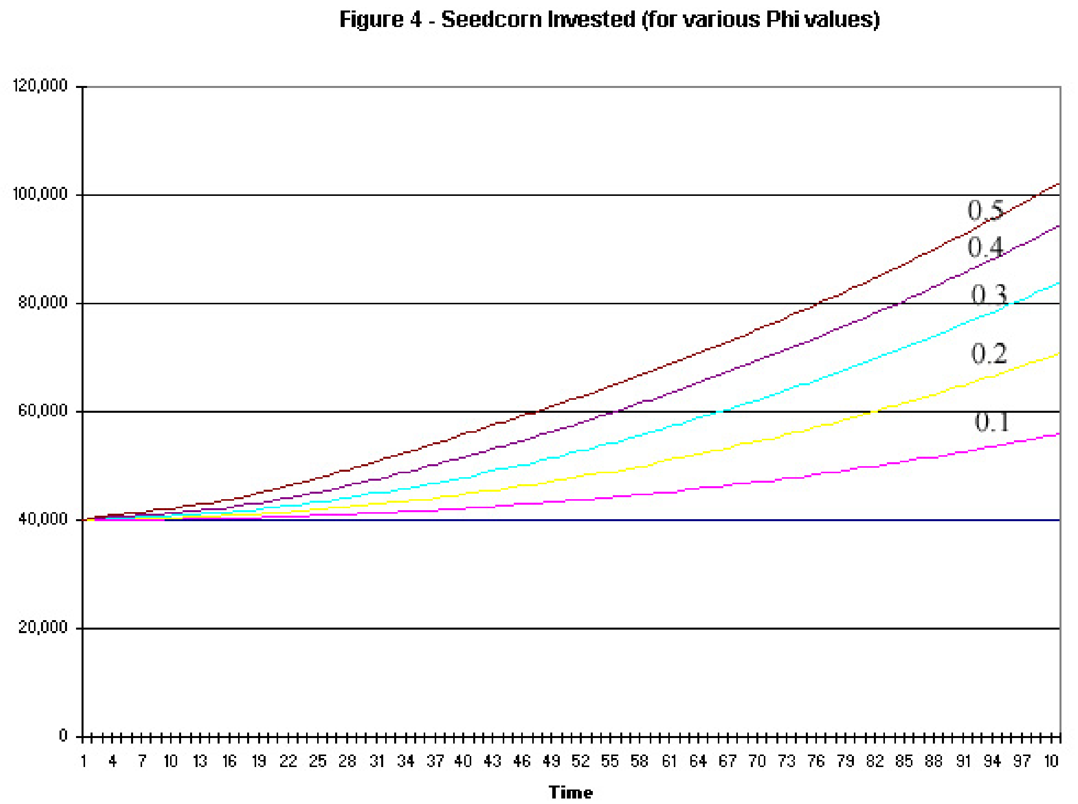
Key based on vertical axis denomination:
Sacks pa - Q (Corn Produced), Qs (Foodcorn Supplied), Qi (Seedcorn Invested),
Dollars pa - R (Seedcorn Invested), J (Interest Bill)
Fieldhands - N (Employment)

FIGURE 3



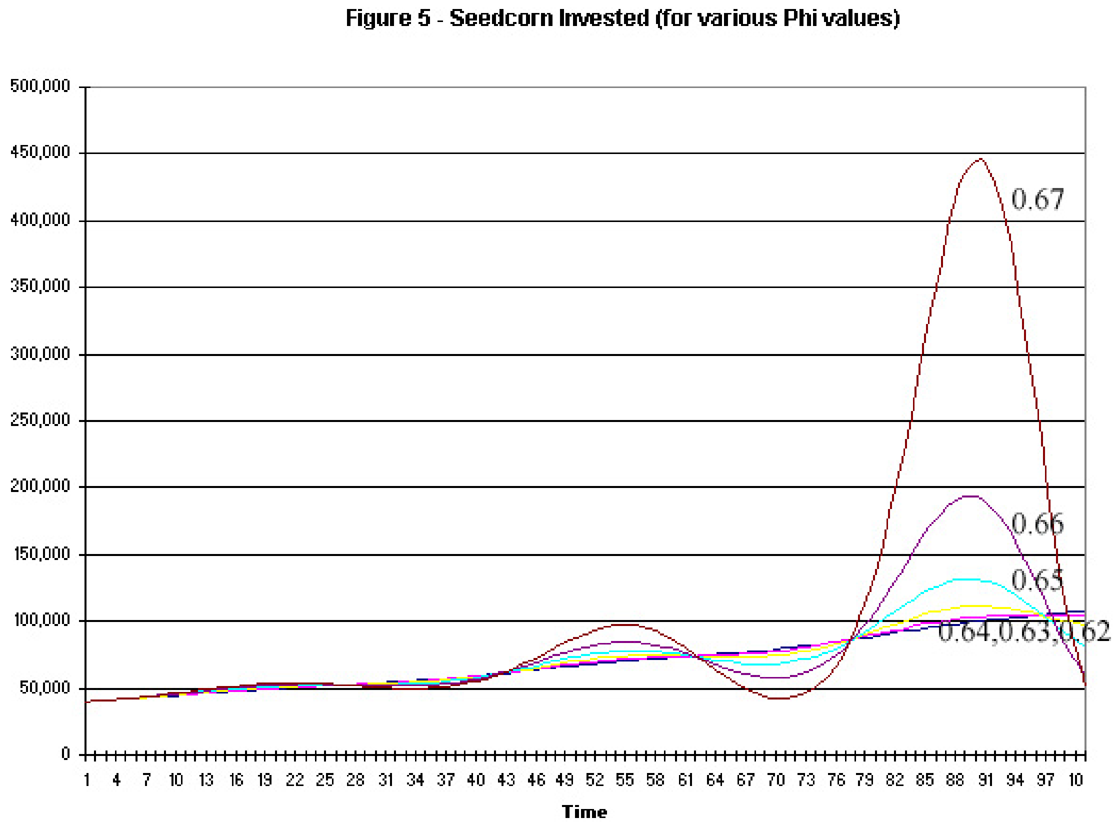
Key based on vertical axis denomination:
Sacks pa - Q (Corn Produced), Qs (Foodcorn Supplied), Qi (Seedcorn Invested),
Dollars pa - R (Seedcorn Invested), J (Interest Bill)
Fieldhands - N (Employment)

FIGURE 4



Key: All ϕ values (0.1- 0.5) are below the critical value of 0.5962.

FIGURE 5



Key: All ϕ values (0.62 - 0.67) are above the critical value of 0.5962.

FIGURE 6

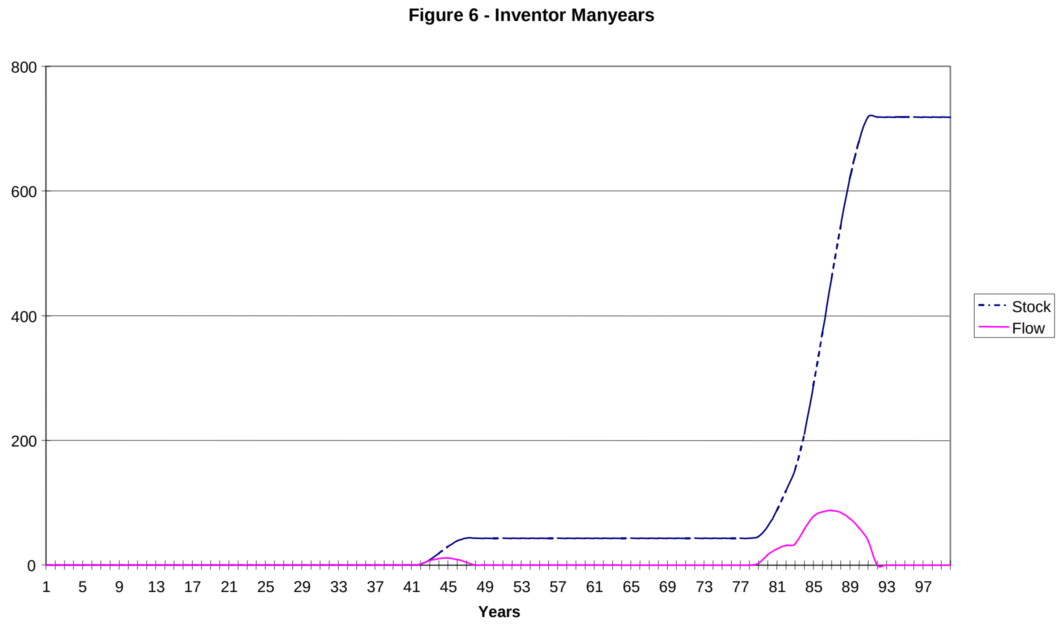


Figure 6 - Inventor Manyears
800
600
400
200
0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Years
Stock
Flow

FIGURE 7

Figure 7 - The Year each Technique is Invented

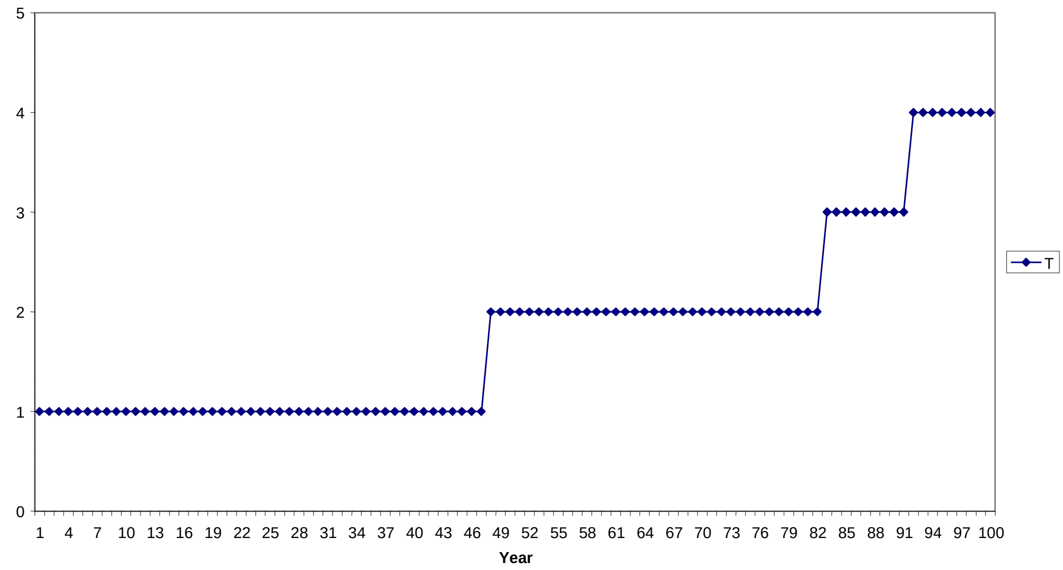
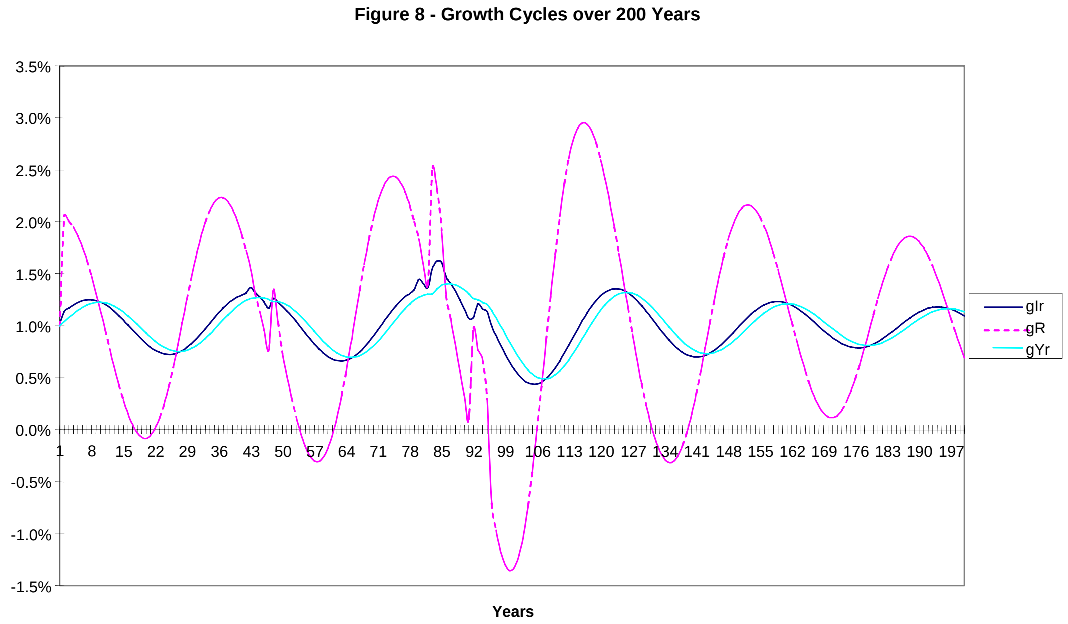


FIGURE 8



Key: Annual % growth rates of - Real Investment (gIr), Realised Profit (gR), Real Gross Product (gYr)

FIGURE 9

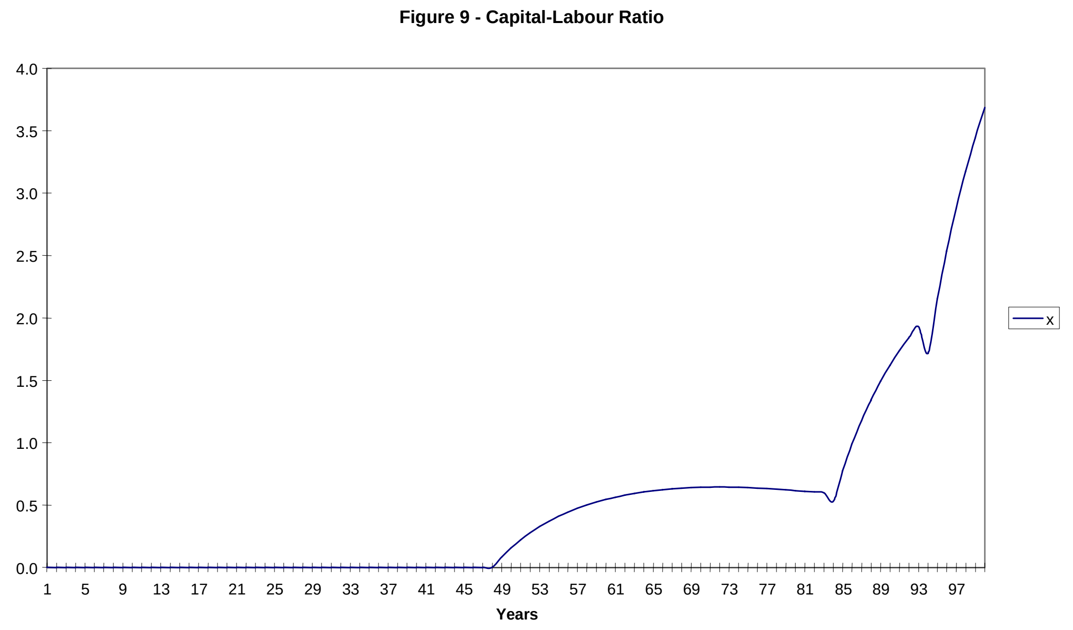
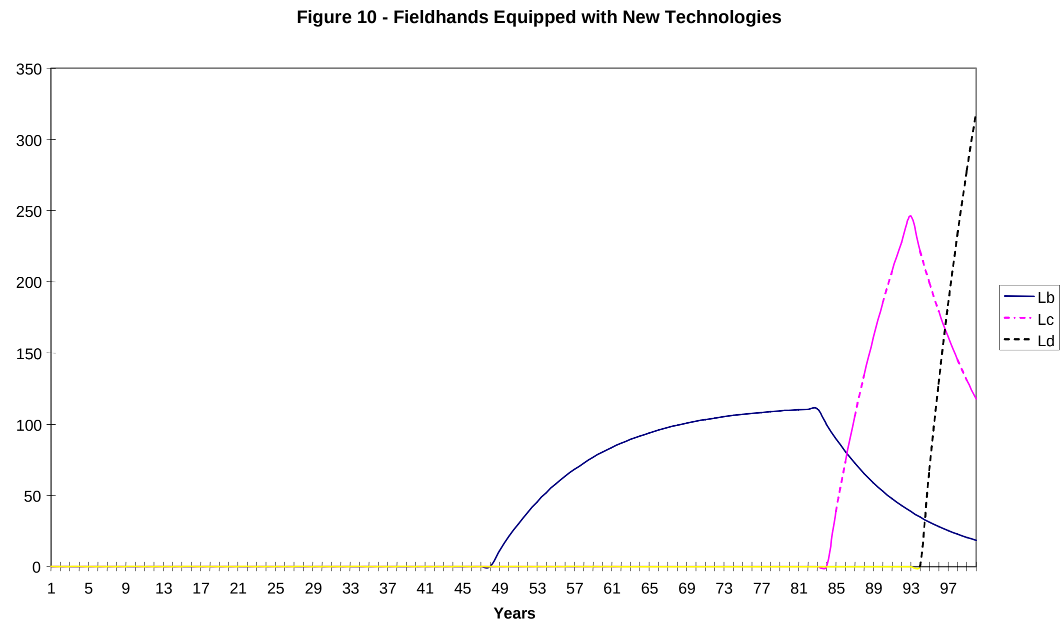


Figure 9 - Capital-Labour Ratio
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
Years
x

FIGURE 10



Key: Fieldhands hired and equipped with technique B (Lb), this begins in year 49
Fieldhands hired and equipped with technique C (Lc), this begins in year 85
Fieldhands hired and equipped with technique D (Ld), this begins in year 95

TABLES

Table 1 – Reduced Form of the Corn-Credit Model

Corn Produced	$Q = \theta\, Qio$	sacks pa	(A')
Seedcorn Invested $Qi = [1 - \phi\{io-\lambda-[(\theta -1)Qio-Qso] / (Qio+Qso/\kappa) + \varepsilon\lambda\theta^2 Qio^2 / No\alpha^2\mu doKo + \lambda\theta(wo-\varepsilon+\rho gpo)Qio / \alpha\mu doKo - \varphi\}]\, Qio$		sacks pa	(B')
Employment	$L = \theta\, Qio / \alpha$	workers	(C')
Realised Profit Rate	$r = \dfrac{(\theta - 1)Qio - Qso}{Qio + Qso/\kappa}$	percent pa	(D')
Corn Price $P = [\theta Qio\{\varepsilon\theta Qio + No\alpha(wo-\varepsilon+\rho gpo)\}\{\varepsilon\lambda\theta^2 Qio^2 + No\alpha^2\mu(io-\delta+\mu)doKo + No\alpha\lambda\theta(wo-\varepsilon+\rho gpo)Qio\}] / No^2\alpha^4\mu^2 doKoQso$		dollars/sack	(E')
Money Wage	$w = wo + \varepsilon\,(\theta Qio/\alpha N - 1) + \rho\, gpo$	\$/worker pa	(F')
Interest Rate $i = \dfrac{\varepsilon\lambda\theta^2 Qio^2 + N\alpha^2\mu(io-\lambda)doKo + N\alpha\lambda\theta(wo-\varepsilon+\rho gpo)Qio}{N\alpha^2\mu doKo}$		percent pa	(G')

Note: To avoid a forest of t-1 subscripts, variables on the RHS that end with a lower-case 'o' to be understood as being lagged by one year. Those on the LHS are current-year values, i.e. normally they carry t subscripts.

Table 2 – The Sequence

Techniques >	**α or A or a**	**β or B or b**	**γ or C or c**	**χ or D or d**
Fieldhand Productivity, in sacks/worker pa	$\alpha = 10.00$	$\beta = 10.04$	$\gamma = 10.09$	$\chi = 10.11$
Inventor Manyears Needed	na	40	100	680
Cumulative Inventor Manyears Needed	na	40	140	820
Employment (Inventors)	0	0	0	0
Invented Yet?	na	No	No	No

Table 3 – Technologies of Corn Production

Techniques >	**α or A or a**	**β or B or b**	**γ or C or c**	**χ or D or d**
Fieldhand Productivity, in sacks/worker pa	$\alpha = 10.00$	$\beta = 10.04$	$\gamma = 10.09$	$\chi = 10.11$
Invented Yet?	na	No	No	No
Artisans Needed to Build one Outfit	na	1	1	1
Gestation Period, in years	na	1	1.5	2
Capital Cost per Outfit, in dollars	na	w	1.5w	2w
Outfits Needed to Equip One Fieldhand	na	1	1	1
Stock of Outfits	na	B = 0	C = 0	D = 0
Fieldhands Hired	La 100%	La 100% Lb 0%	La 100% Lb 0% Lc 0%	La 100% Lb 0% Lc 0% Ld 0%