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An evolutionary economic perspective on technical change and adjustment in cane harvesting systems in the Australian sugar industry*

Lisa Brennan and MalcolmWegener†

Australian sugar-producing regions have differed in terms of the extent and rate of incorporation of new technology into harvesting systems. The Mackay sugar industry has lagged behind most other sugar-producing regions in this regard. The reasons for this are addressed by invoking an evolutionary economics perspective. The development of harvesting systems, and the role of technology in shaping them, is mapped and interpreted using the concept of path dependency. Key events in the evolution of harvesting systems are identified, which show how the past has shaped the regional development of harvesting systems. From an evolutionary economics perspective, the outcomes observed are the end result of a specific history.

1. Introduction

The Australian sugar industry, with its heavy export dependence and direct exposure to the volatility of world sugar prices, has evolved as an efficient, competitive, and low-cost producer of high-quality sugar (Fry 1997; Boston Consulting Group 2003). A significant investment in research and development has enabled the industry to remain competitive through the adoption of innovations aimed at increasing sugar yields, lowering production and milling costs, and improving arrangements for shipping and handling of raw

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† Lisa Brennan is Agricultural Systems Economist, CSIRO Sustainable Ecosystems and Agricultural Production Systems Research Unit, St Lucia, Queensland, Australia. Malcolm Wegener is Senior Lecturer in Agricultural and Resource Economics, School of Natural and Rural Systems Management, University of Queensland, Australia.

sugar. However, despite the industry's status as a low-cost producer of sugar, there appears to be considerable scope to reduce costs by improving the efficiency of the cane harvesting and transport process. A surge of published literature in the 1980s (e.g., Petersen *et al.* 1984; Page *et al.* 1985; Connell and Borrell 1987; Ferguson and Wise 1987; McWhinney *et al.* 1988; Ridge and Dick 1989) suggested that cane harvesting and transport costs incurred by the Queensland sugar industry could be substantially reduced if fewer cane harvesters were used to cut the Queensland cane crop. This assertion was repeated in later reviews, for example Boston Consulting Group (1996), Brennan (1997), Centre for International Economics (2002) and Boston Consulting Group (2003). While harvest-transport inefficiencies have since been addressed in some regions of the industry, they have been difficult to overcome in others.

Sugarcane production in Australia is generally divided into six geographical regions, which are, from most southerly to northerly, New South Wales, Southern Queensland, Central Queensland, Burdekin, Northern Queensland, and the recently established Ord River Irrigation Area in Western Australia. Nearly all of the sugarcane produced in Australia is grown within 50 km of the eastern coastline of Australia, stretching in a discontinuous strip of 2100 km from Maclean in northern NSW to Mossman in far north Queensland.

The Mackay district is one of three that form the Central Region. The other districts in the Central region, Plane Creek and Proserpine, occupy relatively small areas to the south and north of Mackay, respectively. The cane-growing area supplying the four mills in Mackay is located in the Pioneer Valley west of the Queensland city of Mackay. The district is separated from other parts of the Central region by natural geographical boundaries. As the second largest cane producing area in Australia, the Mackay district, with approximately 1300 growers supplying four sugarcane crushing mills, and occupying over 70 000 hectares, is a significant component of the Australian sugar industry.

Compared to the adjustments that had already taken place in other cane producing districts in Australia by the mid-1990s, the rationalisation of the harvest-transport sector in the Mackay district had been particularly slow, so the district had been unable to achieve the economies of size that had already been achieved in most other cane producing regions. In Mackay, costs have been higher than they could be because of poor use of both harvesting equipment and the mill transport system. The reasons for this include harvest-transport systems operating for restricted periods each day, small harvest group sizes (a group is the farm or farms harvested by a single operator, usually with one mechanical cane harvester), and slow diffusion of new harvesting technology. The potential to reduce harvesting costs by increasing group size has been demonstrated by Brennan *et al.*

(1997). Brennan (1997, 1999) also conducted a detailed assessment of costs to the Mackay sugar industry of harvesting and transporting cane from fields to the mill under a wide variety of potential harvesting and transport configurations. Changing the number of harvesting groups, spreading the hours for group harvesting, and increasing the investment in mill transport infrastructure, as well as improving in-field harvesting conditions, appeared to impact on the efficiency of harvest-transport systems. The analysis of costs for a single case study mill area in Mackay revealed that fewer, but larger, harvesting groups operating high-capacity equipment over an extended cutting period, coupled with upgraded locomotive capacity and fewer cane collection points on the mill transport network, could significantly reduce the costs of in-field harvesting operations and mill transport procedures. The total cost saving to the one mill area, alone, could amount to almost $AUS 2.5 million per annum. Other studies have reported similar findings (Boston Consulting Group 1996).

Since commercial adoption of mechanisation in the sugarcane harvesting process began in the 1950s, the Australian sugar industry has made ongoing adjustments to incorporate new technology into harvesting and transport systems. These adjustments have been characterised by a high level of interdependency between the cane production/harvesting and milling sectors. Another feature has been the entrenchment of regional trends that emerged in the 1950s. In Mackay, the expected incorporation of high-capacity harvesting machinery coupled with upgraded mill transport infrastructure did not take place as quickly as in other areas. What reasons then might explain the Mackay industry's failure to adopt the technology necessary to permit it to achieve a low cost outcome?

In the present paper, this question is addressed by taking an evolutionary approach to economic investigation. Past events in the Australian cane harvesting sector that may have set the pattern for regionally distinct development paths in the Australian harvest sector are explored. It is hypothesised that the dynamic process of incorporating new technology into harvesting systems, and the industry's response to technology, takes on an essentially historical character. The development of harvesting systems, and the role of technology in shaping them, is mapped and interpreted using concepts of path dependence and lock-in by historical events. Key events in the evolution of harvesting systems are identified which show how the past has shaped the regional development of harvesting systems.

2. Evolutionary perspectives on technical change and diffusion of innovations

The contemporary interest by economists in evolutionary theories that explain the incorporation of new technology in economic systems is often credited to the seminal works of Nelson and Winter, particularly Nelson and Winter (1982). Their work is representative of the rise of a new group of evolutionary economists who rejected static, neo-classical general equilibrium depictions of the economy (Ruttan 1997; Foster 2001). Evolutionary theories challenge a number of neo-classical assumptions, particularly the postulate of profit maximisation. They deny this postulate by assuming that the choice between possible actions follows a different logic or by denying that there is any choice to be made. Economic and technological change are acknowledged as being causally intertwined – 'that at any given moment the uses to which scarce resources are put in an economy depend heavily on the current technology' Hall (1994, p. 1). Evolutionary theory asserts that there are some mechanisms of dynamic adjustment that are radically different in nature from those allocative mechanisms proposed by neo-classical theory. Also acknowledged is the role of the socio-institutional framework and the way it influences technical and structural change. The rate of technical and structural adjustment relates not only to market imperfections, but to the nature of markets themselves and the behaviour of their agents (Freeman 1988). Furthermore, the evolutionary approach contrasts starkly with the neo-classical approach by its explicit account of the observation that all members of a population are different from each other, rather than using the representative unit (Hall 1994). Analyses conducted under the evolutionary approach recognise this variation because it is seen as a central means of explaining how systems change.

Neo-classical theory has been recognised as an appropriate tool for equilibrium analysis of economic systems, including intertemporal equilibria, steady-state growth, and other phenomena that take place in logical, as opposed to historical, time (Elster 1983). However, the theory has been criticised for its inability to deal with dynamic problems. One of the earliest critiques in this regard (David 1975) was set in an agricultural context in reaction to considerable published literature from agricultural economists on the bias of technical change among labour-saving and land-saving directions within the confines of the standard two factor (labour and capital) neo-classical model (Ruttan 1997). David (1975) insisted that such analyses needed an evolutionary, historical approach. His assault on the explanatory power of neo-classical theory captures the essence of such criticisms:

> The economist's now conventional conceptualisation of technological innovation as a change of a neo-classical production function – an alteration of relationships between inputs and outputs across an entire array of known techniques – has turned out to be less helpful than one might wish. On more than one occasion, regrettably, it has

led historical discussions of invention and diffusion into paradox and confusion.

(David 1975, p. 2)

2.1 Path dependence

David's (1975) work opened the door on what has become known as the path dependent model of technical change, which places importance on the sequence of specific microlevel historical events (Ruttan 1997). He described a path-dependent sequence of economic changes as being 'one of which important influences upon the eventual outcome can be exerted by temporarily remote events, including happenings dominated by chance elements rather than systematic forces' (David 1975, p. 332).

Path dependence recognises that 'history matters' (David 2001): past technological achievements influence future achievements via the specificity of the knowledge that they entail, the development of specific infrastructures and the emergence of increasing returns of various kinds from technological options (Dosi 1991). In other words, the state of the firm/industry at period $(t + 2)$ depends at least partly on events specific to the state at $(t + 1)$, and those at $(t + 1)$ to events at t. Outcomes at any given moment depend on how the system got there, that is, the path it took. What happens next is always heavily constrained by what has already happened; the future can only ever be built upon the past (Hall 1994).

Arthur (1989) advanced the path dependent model of technical change by exploring the dynamics of competing technologies in situations when more than one type of new technology arrives at the same time in the market. He explored how 'random events' occurring during adoption could influence the selection of successful technology, and how some sets of random historical events may cumulate to drive the adoption process towards a one-market share outcome. He also examined how increasing returns might drive the adoption process into developing technology that has inferior long run potential, even when superior options might be available. Two properties emerged from the dynamic approach of the Arthur (1989) study: inflexibility*,* in that once a dominant technology begins to emerge it becomes progressively 'locked in'; and nonergodicity*,* meaning that historical 'small events' are not balanced out or forgotten by the dynamics but, rather, they decide the outcome. Historical accidents therefore cannot be ignored (David 1985). David (1985, p. 332) also defined nonergodicity as 'stochastic processes that do not converge automatically to a fixed point distribution of outcomes'. Dosi and Orsenigo (1988, p. 24) examined how technological evolutionary paths could be affected by small 'deviant' behaviour which, 'under certain micro and/or macro economic conditions, become autocatalytic, progressively amplify and may end up being dominant'.

Arthur's work highlighted lock-in as a set of conditions which, in a path-dependent system, make it either impossible or highly unattractive to move from one state to the next in more than a very narrow range of ways, with the technological consequence of confining innovation to a narrow corridor of developments favouring firms with particular sorts of experience over those who lack it (Hall 1994).

The potential inefficiency occurring from this is that a particular path might be inferior in terms of some welfare measure but the system may still be 'locked' in to it. Arthur (1989) proposed that lock-in arises because of increasing returns to scale in knowledge, noting that modern, complex technologies often display increasing returns to adoption. The more they are adopted, the more experience is gained with them and the more they are improved. Related to this concept is the idea that the probability of adoption rises with the market share of the technology. The relative advantage may come about through externalities brought about by a larger group of users, as well as the improvements in performance generated by cumulative learning. Other scholars in the field of diffusion research have reported on 'learning by using' (Arrow 1962; David 1975; Rosenberg 1982). Arthur (1989) suggested that this could explain why one technology could dominate over competing technologies. With increasing returns, the advantage gained from individually insignificant events during adoption may give a particular technology an initial advantage over the other technologies.

Interrelatedness is another reason why lock-in may occur. Existing production skills associated with a technology build up over time and abandoning an existing production method to adopt new ways of doing things implies abandoning other technologies as well. Interrelatedness describes the dependence of benefits from adoption on a firm-specific environment in which the innovation is to operate. As Metcalf stated:

> A new capital good typically has to be operated in conjunction with the existing equipment of the firm, and if the latter must be altered in any way to accommodate the innovation, the additional costs of adjustment must be added to the capital cost of the innovation. In this way, interrelatedness limits the scope for adoption. Interrelatedness factors should not, however, be limited to physical effects alone. Account should be taken of interrelatedness between an innovation and existing labour and management skills and their organisational context, and between an innovation and the composition of the adopter's output.
>
> (Metcalf 1988, p. 565)

In a classic, although hotly debated work, David (1985) illustrated a path-dependent sequence of economic changes using the current layout of keyboards, the top line of which has the sequence of keys QWERTYUIOP.[1] He used the concept of interrelatedness to explain the dominance of QWERTY keyboards over more efficient alternatives. Technical interrelatedness referred to the need for system compatibility between the keyboard and a touch typist's memory of a particular arrangement of keys, such that the expected present value of a typewriter was dependent upon the availability of touch typists familiar with a particular arrangement of keys.

David (1985, p. 336) noted that the case of the QWERTY keyboard is one of an industry driven 'prematurely into standardisation on the wrong system – where decentralised decision making subsequently has sufficed to hold it'. Other features which caused QWERTY to lock-in were economies of scale and quasi-irreversibility. Arthur (1989), David (1985) and Landon (1975) recognise that lock-in is irreversible, or quasi-irreversible, to the extent that it is measurable by the transition or adjustment cost to change over. The relevance of economies of scale was that the overall user costs of a typewriter system using QWERTY tended to decrease relative to other systems as it gained acceptance. The main consequence has been the tendency for the process of competition between manufacturers to lead towards defacto standardisation through the predominance of a single keyboard design.

The seminal contributions of David and Arthur are still widely used to illustrate the concepts of path dependency and lock-in, although this work in the 1980s also opened up the way for a growing literature concerned with the analysis of the evolution of economic phenomena, with path dependence now a familiar theoretical concept (Garrouste and Ioannides 2001). There is now a branch of present day economics known as 'evolutionary economics' and there is a journal of the same name. Several books on the subject are in print (Laurent 2001). Yet more than two decades after David's (1975) criticisms concerning the 'timelessness' of neo-classical economic theory, some contemporary contributions to the published literature continue the criticism that 'mainstream' 20th Century economics has carried on as if its subject matter could be safely assumed to be independent of history and essentially timeless (David 2001; Garrouste and Ioannides 2001).

[1] Debate has followed Liebowitz and Margolis (1990, 1999) critical treatment of David's QWERTY. David has addressed such criticisms, e.g., David (2001). Ruttan (1997) states that the Liebowitz and Margolis criticism has largely been ignored by the proponents of path dependence.

3. 'Evolutionary' explanations of adjustment and technology diffusion in the sugarcane harvesting sector

3.1 Industry organisation

Approximately 95 per cent of Australia's cane farms are owned and operated by sole proprietors or family partnerships with the remainder operated mainly by private companies. Sugar milling companies own less than 2.5 per cent of total cane area (Canegrowers 2003). For harvesting, farms are formed into groups. A group is a single harvesting contract and includes the farms (or farm) harvested by a single harvester operator. Groups may be formed by mutual arrangements by growers, subject to the approval of the mill. Growers may cut their own cane, or arrange to have it cut by a contractor.

Most of Queensland's 26 sugar mills (raw sugar factories) and the three in New South Wales were established more than 100 years ago and are cooperatively owned by growers or proprietary companies. In addition to producing raw sugar, mill responsibilities include coordination of harvesting, transport of sugar cane (mainly using narrow gauge railway), sampling and analysis of cane, delivery of sugar to bulk storage terminals, and maintenance of accounts to allow pool payments to be made to growers.

The Australian raw sugar industry is often considered to be comprised of two sectors: sugarcane growing and sugarcane milling. The interdependent relationship between growers and mills in relation to harvesting and transport arrangements, as well as other aspects of growing and milling, reflects the highly regulated nature of the industry over the last 100 years. Almost every aspect of cane growing, milling and marketing are subject to rigid controls regulated under the Sugar Industry Act 1999.

Historically, the industry has operated under regulations which control the land on which cane may be grown, determine the terms of harvesting and delivery conditions, specify the mill to which it must be delivered, and provide the framework for distributing revenue between growers and millers. Under such controls, growers and millers have had little scope to negotiate the price, quantity or terms of delivery for cane. Compulsory acquisition underpins the regulations, centralising control of raw sugar marketing. Following several industry reviews in the 1980s and 1990s demonstrating the gains from legislative change, the Sugar Industry Act 1991 and Sugar Industry Act 1999 liberalised some of the regulations, although many have remained unaltered (Centre for International Economics 2002).

It has been argued that the system of production control, known as the assignment system, impacted on harvesting efficiency. The cane land assignment system was introduced in 1926, and has been the principal constraint on the amount and location of sugar production in Queensland. Assignment essentially bound the grower and the miller in a contractual arrangement. In the 1950s, the availability and cost of labour were major constraints on the expansion and improved efficiency of the industry, and the size of farms during the hand-cutting era was dictated largely by the task of managing harvesting in these conditions. The introduction of mechanical harvesting meant that land assignments replaced labour availability as the major constraint on farm size (Connell and Borrell 1987). Until the recent reviews of the Sugar Industry Act,[2] the assignment system strictly controlled where and how much cane could be grown in Queensland. Although cane production had approximately doubled in the 10 years after the move to mechanisation of the harvest, farm size did not increase proportionately, and the extra production was partly because of new entrants to the industry and mainly came from increased cane yields. The Industry Commission (1992) suggested that, despite gradual increases in harvester capacity, small group harvesting might have been perpetuated by the practice of granting small areas of assignment. Connell and Borrell (1987) argued that the introduction of mechanical harvesting could have released growers from their involvement in cane harvesting and allowed them to specialise in growing much larger crops while leaving harvesting to contractors. Instead, production controls, which were set in place before mechanisation of the harvest, prevented this expansion, and the opportunity cost of growers' own labour was forced downward. For many growers, the next best use of their time and labour which could not be spent producing more cane was to harvest their own cane.

3.2 Influence of premechanical harvesting arrangements on harvesting group size and structure

Driven by acute labour shortages (Connell and Borrell 1987), the rapid investment in mechanical harvesting equipment that took place from the 1950s changed the industry from a labour-using to a capital-using system; and group harvesting evolved as a structural response to this. Prior to mechanisation, harvesting groups were small in all regions because manual harvesting was a slow process. During the late-1950s and early-1960s, ownership of harvesters was largely confined to individual growers purchasing their own machines (Vallance 1968b, 1969, 1972). However, with the rising cost of purchasing and maintaining harvesting equipment, and the ability of mechanical harvesters to cut cane much faster than manual labour,

[2] With the introduction of the Sugar Industry Act 1999, 'assignments' were replaced by cane production areas.

Table 1 Age distribution of harvesters as a percentage of regional total (1995)

Harvester age (years)	North	Burdekin	Central	South	NSW
0–3	33.6	54.7	14.9	19.3	61.3
3–5	8.6	4.3	5.8	3.3	9.7
5–10	32.5	20.1	17.3	15.1	19.3
> 10	25.3	20.9	62.0	62.3	9.7

Source: Austoft data, unpublished.

Table 2 Average group size by district (tonnes per harvester)

Year	North	%[a]	Burdekin	%[a]	Central	%[a]	South	%[a]	NSW	%[a]
1970	11 873		12 582		6137		6522		na	
1975	14 780	24	23 149	83	9882	61	9353	43	18 535	na
1980	15 742	7	25 176	8	9814	0[b]	10 649	13	31 465	70
1985	16 679	6	26 808	6	8923	0[b]	12 112	14	31 338	0[b]
1990	23 566	41	35 827	33	12 774	43	13 895	15	37 359	19
1995	39 589	67	49 896	40	20 820	63	19 478	40	65 454	75

[a]Per cent increase from the previous five years; [b]average group size fell slightly from previous year; na, not applicable. Source: adapted from Brennan *et al.* (1997).

growers quickly found alternatives to sole ownership of equipment, including cooperative group ownership by a number of farmers and contracting arrangements with other growers. Independent contractors also offered contract-harvesting services. With widespread adoption of mechanical harvesting by the late 1960s, there was a general trend in many parts of the industry for group sizes to increase. Groups enlarged to provide sufficient cane supply for the harvesters because the capital cost of the equipment was large relative to the tonnages that were cut manually. This trend continued as the incorporation of new harvesting equipment involved expenditure on large capital items that are indivisible, making their purchase difficult to economically justify for smaller enterprises (Brennan *et al.* 1997). This ongoing formation and gradual amalgamation of mechanical harvesting groups, resulting in fewer but larger groups (and fewer cane harvesters) in the industry, has been a major feature of harvest-systems evolution. The Mackay sugar industry has lagged behind most others in terms of the extent and rate of incorporation of new technology into harvesting systems (as represented by the Central region in table 1), and small group harvesting persisted in Mackay while other regions generally adjusted to larger groups (table 2).

The origins of this situation are, in part, revealed by examination of the premechanical harvesting arrangements in Mackay. In the two areas that have been slow to adjust to large group sizes – Mackay and the Southern

Table 3 Machines operated in various ownership categories[a] for Queensland districts, 1967–1969 (per cent)

	A			B			C		
Region	1967	1968	1969	1967	1968	1969	1967	1968	1969
Far north*	23	28	24	68	62	66	9	10	10
Herbert*	9	9	9	30	30	34	61	61	57
Burdekin	10	8	8	49	48	45	41	44	47
Central	41	40	34	27	29	38	32	31	28
South	41	37	25	40	42	51	19	21	24
QLD	31	31	25	43	42	47	26	27	28

Source: adapted from Vallance (1970b, pp. 568). *North region comprises the Far north and Herbert districts; [a]A, growers cutting own cane only; B, machines owned by a growers or a group of growers which harvest a group of farms; C, machines owned by non-farmer contractors.

region – historically, there has been a strong tendency toward individual group harvesting (table 3) (Vallance 1970b). Prior to mechanisation, most cane production regions had teams of cutters that moved from farm to farm. It has been documented that Mackay's history of having a high proportion of resident farm labour participation in the harvest has militated against the formation of large harvesting groups (Willis 1972; Connell and Borrell 1987). With the introduction of mechanical harvesters, a large proportion of growers in Mackay continued to cut their own cane, simply replacing manual labour with machinery. This group structure meant that machine throughput was low compared to other regions.

Harvesting technology developed in a manner that permitted the establishment and perpetuation of a range of harvest group structures. In the decade after the release of the first commercially available harvester, the range of harvester makes and models available was much wider than is currently the case, reflecting the high level of inventive activity within the industry (Kerr and Blyth 1993).

Mechanical loaders, which loaded bundles of wholestalk cane onto railway wagons, were the first widely adopted mechanical innovation in the cane harvesting system and represented a major transitional step between manual harvesting and full mechanisation, and eliminated the most 'burdensome' of the manual harvesting operations. Mechanical loading was adopted throughout the Australian sugar industry from 1955 onwards, and most rapidly in Mackay, encouraged by the arrangement of relying on resident farm labour for harvesting (Department of Labour and National Service 1970).

In the 1960s, a grower could choose from either a 'wholestalk' harvester, which was operated in conjunction with a mechanical loading machine, and was the first type of harvester to be adopted, or a 'chopper' harvester which

Table 4 Mechanically harvested cane cut by chopper (C) and wholestalk (W) harvesters in Australian sugar regions (per cent)

	North		Burdekin		Central		South		NSW	
Season	C	W	C	W	C	W	C	W	C	W
1962	95	5	100	0	73	27	15	85	–	–
1963	98	2	97	3	82	18	10	90	–	–
1964	99	1	100	0	93	7	13	87	–	–
1965	99.8	0	71	29	70	30	13	87	–	–
1966	98	2	43	57	68	32	16	83	50	50
1967	95	5	50	50	68	32	25	75	100	0
1968	94	6	45	55	72	28	43	57	100	0

Source: Department of Labour and National Service (1970, p. 41).

chopped the cane into short lengths and loaded it into trailer bins ready for transport to the mill. Both types were available in a range of harvesting capacities. Table 4 shows that during this period, there was a relatively high retention of wholestalk machines in Mackay and the Southern region. Despite the availability and suitability of chopper harvesters, this high retention of wholestalk machines in Mackay was attributed to the small group structure stemming from preferences to cut their own cane (Vallance 1972). Another explanation of this is presented in the next section. The greater range of harvesting equipment available enabled a wide range of harvest group structures to evolve. The availability of small capacity, less expensive harvesters enabled many growers in Mackay to buy these harvesters and continue harvesting their own cane.

Expectations of future technological developments and the rate of technological change influence diffusion (Dosi 1991) and it is possible that the technological expectations that prevailed during the early days of mechanical harvesting contributed to reinforcement of the small group structure in Mackay. In popular industry publications during the 1960s, the practice of cutting one's own cane was recommended as cost effective and managerially sound and there were suggestions that harvesting technology would be refined to suit this practice (Vallance 1967, 1968b). It was not evident until the late 1960s that the large capacity chopper harvester would become the dominant design and growers and millers may not have fully anticipated this outcome when they were making long-term investment decisions.

By 1972, the nature of harvesting equipment available to the Australian sugar industry was changing. The labour-saving large-capacity chopper harvester became established as the dominant design in the Australian industry, and almost all mill areas converted completely to the receival of chopped cane from their supply areas (Churchward and Belcher 1972). By this time, many harvesting groups were well established and there was very little formation of groups that were buying their first harvester. The sale of new harvesters was largely restricted to the replacement of older machines (Vallance 1972). There were two main effects from this. First, the maturation of the harvesting sector meant that demand for new machines changed. Sales of new, medium-capacity harvesters dropped because they competed with second-hand machines that could be easily repaired and modified by growers (Vallance 1968a), and the competition cemented the high-capacity harvester in its dominant technological position. Second, the availability of cheap second-hand machines meant that small groups could continue to operate economically.

In Mackay, this meant that many growers who established operations to harvest on a cut-own-cane basis continued to do so despite the availability of high capacity harvesters. While the reasons for this would have varied from farm to farm, one possibility is that growers identified significant transaction costs and insufficient benefits involved in adopting alternative harvesting arrangements. Capital tied up in existing farm machinery may have provided a barrier to producers taking advantage of new technological developments.

As highlighted in the previous review, as more experience is gained from using a technology, it is more likely to become the dominant technology. Unlike other regions, Mackay growers were experienced in operating their cane farms using their own labour to harvest cane, and increasing returns probably resulted from refinement, over time, of the input mix involved with cutting their own cane as well as growing it. This could maximise their farm management objectives. In other words, it is through 'learning by doing' that Mackay growers' familiarity with the use of permanent farm labour for harvesting, rather than rotational harvesting arrangements, has given the existing arrangement an advantage over alternatives. For Mackay growers, the transaction costs of moving from using permanent farm labour to a group structure for harvesting could well have been higher than for growers in other regions whose experience grew in the direction of operating their farms using rotational harvesting arrangements. Manual harvesting arrangements in Mackay appear to have contributed to setting the region on a path to reinforce the small group structure, which has persisted (table 5).

In Mackay, individual harvesting systems therefore effectively 'competed' with larger harvesting group structures in the harvesting 'market'. Manual harvesting gave the small, individual farmer in Mackay an initial advantage, and the experience gained in operating small cut-own-cane groups was reinforced by the availability of harvesting technology permitting this arrangement. This meant alternative harvesting systems became less attractive and became locked out of the harvesting market.

Table 5 Ownership categories by region, 1995 season

Ownership category	Grower cut own cane		Grower and contractor		Cooperative		Cooperative and contract		Independent contractor	
District	%[a]	%[b]	%[a]	%[b]	%[a]	%[b]	%[a]	%[b]	%[a]	%[b]
North	12.5	5.6	52.1	60.4	3.1	2.4	8.3	2.4	24	29.1
Burdekin	2.9	0.4	25.7	25.6	0	0	0	0	71.4	74
Central	33.5	13.6	35.7	32.5	9.7	11.7	1.5	11.7	19.5	30.5
South	na	na	na	na	na	na	na	na	na	na
NSW	0	0	0	0	100	100	0	0	0	0

[a]Per cent of total groups; [b]per cent of total crop; na, not applicable.
Source: adapted from Brennan *et al.* (1997).

3.3 Systems interrelatedness

The following examples, of investment in mill transport systems and interaction of machinery with geographical conditions, show how David's (1985) concepts of technical interrelatedness and irreversibility reinforced the development of regional industries along set trajectories, in terms of harvesting group size and structure.

3.3.1 Investment in mill transport systems

Before the advent of mechanical harvesting, the raw sugar mills in Queensland were able to operate efficiently by allowing the individual farmers to arrange their own manual harvesting groups. Hourly crushing rates at mills were low, cane deterioration was not recognised as a serious problem, and it did not matter that cane supply was slow, neither was it crucial for tight control to be kept on the activities of these groups (Connell and Borrell 1987). Cane could be left in the field until it was required at the mill. Using temporary infield tramways, a relatively large number of wagons could be loaded and left waiting until a locomotive was available to haul them away.

The transition to chopper harvesting was a major departure from wholestalk harvesting. The realisation that deterioration of cane was much more rapid and severe with chopped, burnt cane came slowly. In the first published paper on deterioration in chopped sugarcane, Young and Vallance (1959) emphasised the necessity for greater coordination between mills and growers. Mill transport systems evolved to keep pace with harvester development (Ridge 1987). Bins were designed to hold chopped cane, the rail network expanded in most mill areas, and portable line disappeared from cane blocks to be replaced by permanent railway sidings and roll-on/roll-off trailers or road transport. Controlled schedules were devised to collect cane and mills imposed tight controls on harvesting arrangements to address cane deterioration, availability of bins, transport scheduling and wet weather harvesting.

Such controls have also impacted on the rate and nature of diffusion of chopped cane harvesting, as did the producer choices outlined in the previous section. For example, it was common for mills to impose controls on infield harvesting arrangements to address problems arising from harvesting in wet weather, such as high extraneous matter levels, lost milling time, and difficulty maintaining fairness in allocating harvest quotas. For many years, the mills in Mackay managed wet weather problems by encouraging more harvesters to operate than needed, encouraging the operation of small groups (Ferguson, pers. comm., 1994). Also, harvester reliability during the period of innovation and development was not up to the standard of modern machines and the existence of many small groups acted as a form of insurance against harvester breakdowns which could slow the flow of cane into the mills (Connell and Borrell 1987).

The mills' requirement for clean cane deliveries always provided difficulties in the development of suitable harvesting machines. The increased popularity of the chopper harvester had important implications with respect to cane quality. Mills initially experienced difficulties processing large quantities of chopped cane and preserving sugar quality. For the mill, another problem associated with widespread adoption of chopped cane harvesting was the need to invest heavily in tramway bins to hold the chopped cane billets. Growers could not use chopper harvesters unless bins were provided.

The construction of mill transport infrastructure therefore had to occur more or less simultaneously with rapid diffusion of chopped-cane harvesting. Initially, the mills could only accept limited quantities of chopped cane without the necessary transport infrastructure. Likewise, all growers in a mill area could not supply chopped cane until the mill made a large investment in cane bins. Consequently, despite the growing demand for chopper harvesters by growers, restrictions were placed on the number of chopper harvesters that could supply cane to the mill. Controls on the use of chopper harvesters were established in several districts and were particularly restrictive in the Central region (Vallance 1968b). Restrictions were gradually eased and by 1974 most Mackay growers supplied chopped cane. The transition to full chopped cane harvesting, however, occurred later than in other parts of the Australian industry. Similar tight restrictions were imposed on the use of chopper harvesters in the Southern region (Department of Labour and National Service 1970), which also has a history of small harvesting group size and old machinery. A contrasting case is the Northern region which, like Mackay, had suitable field conditions for the use of the chopper harvester, and no mill restrictions preventing the widespread adoption of chopper harvesters (Willis 1972). Group sizes in this region have historically always exceeded those in Mackay and the Southern region. Restrictions on chopper harvesters had a large impact on machinery purchases in Mackay: a complete changeover to chopped cane harvesting would have occurred earlier if restrictions had not been imposed on the growers (Kerr 1988). Many Mackay growers had no choice but to persist with wholestalk harvesters rather than adopt the larger-capacity chopper harvesters. This may have contributed to reinforce the small group situation. In other districts, restrictions also impacted on the adoption patterns. Vallance (1968b, p. 686) wrote 'it is certain that the initial introduction of wholestalk machines to some [] areas would not have occurred had it been possible for the growers concerned to obtain chopper machines.'

The other aspect of mill infrastructure requirements to handle chopped cane was the construction of tramway sidings, approximately one per farm, to hold both empty cane bins as well as those already filled by the harvester and waiting to be taken to the mill. The construction of sidings during the 1960s accommodated the prevailing group structure. This was expensive infrastructure and quasi-irreversible because the long-term nature of the investment meant that the location and capacity of sidings were not likely to be significantly changed once constructed. Present siding locations in the Mackay system have remained largely unchanged for decades (Cane inspector, Racecourse Mill, pers. comm., 1994).

In Mackay, tramway sidings were never large because the mill transport infrastructure did not have to service large groups – in contrast to other regions, where the sidings needed to be longer. This happened because harvesting and associated work on farms in Mackay usually took place in small batches each day rather than farmers interspersing full days of harvesting with periods of related activities. Cane delivery scheduling therefore involved the delivery and pick-up of a small number of wagons to and from a large number of farms each day (Connell and Borrell 1987). The construction of small railway sidings encouraged the continued supply of small cane batches because the sidings could not accommodate the output from large harvesting groups.

3.3.2 Geographical influences and the penalties for taking the lead

Another example of the problem of interrelatedness is that the rate of diffusion of harvesting technology was significantly affected by the interaction of the technology with the geography. A major challenge for the Australian sugar industry was the development of machines that were able to handle the differences between localities, terrain, soil, climate, as well as different types of cane, including the sprawling crops, that occurred throughout the

Table 6 Proportion of cane mechanically harvested in Australian sugar regions (per cent)

Season	North	Burdekin	Central	South	NSW
1961	7	1	3	9	–
1962	14	1	4	12	–
1963	23	2	5	16	–
1964	37	3	14	30	–
1965	54	9	36	43	< 0.5
1966	57	22	46	55	< 0.5
1967	65	34	55	71	1.0
1968	72	58	72	81	2.0

Source: Department of Labour and National Service (1970, p. 40).

industry.[3] Although conditions for mechanical harvesting in Mackay were generally suitable enough for new harvesting technology to be used as it became commercially available (Willis 1972), poor infield harvesting conditions, particularly heavy, clay soils, had the effect of retarding the rate of diffusion of harvesting technology into other areas, particularly the Burdekin region (Willis 1972), and completely precluded its introduction into the NSW region until solutions had been developed to overcome infield operating difficulties (Vallance 1970a).

Although the Burdekin and NSW regions were latecomers to mechanical harvesting (table 6), harvesting arrangements have evolved more efficiently than for other regions. Both regions now have the largest harvesting groups in Australia. Considerable areas of cane growing land in the Burdekin region were assigned well after the introduction of mechanised harvesting. Aided by larger farm sizes, farm development could be designed to meet harvestability criteria, such as long rows.

Similarly, the large groups currently operating in the NSW industry suggest that this region benefited from the late adoption of mechanical harvesting which did not occur there until the mid-1970s. The system changes in the Mackay industry occurred on an ad hoc basis: the infield transport and mill infrastructure were gradually modified as new technology became available. In contrast, the transition to mechanical harvesting in NSW was

[3] In another agricultural example, David (1975) also noted that the man-made physical farm landscape impacted on diffusion patterns for agricultural machinery. Specifically ridge and furrow agriculture placed an initial obstacle in the path of farm mechanisation in the UK. He identified interrelatedness in relation to the mutually complementary nature of activities, such as grain harvesting on British farms, with techniques used for drainage, wind damage control, and on-farm transportation of field equipment (David 1975). Any capital goods used for these activities must have been mutually compatible before adoption could occur. A case study with a similar theme is Veblen's (1915) work on the problems of undersized railway wagons in Britain and the penalties for taking the lead in adoption of innovations.

rapid, coordinated, and contrasts strongly with the continuous incremental changes that occurred in many Queensland districts. The transition in NSW involved a radical change in the system because the previous mill transport arrangement, largely based on river punts, could not be refined and upgraded to accommodate chopped cane. The NSW industry was a late entrant into mechanical harvesting because a leap to a new technical paradigm was required. By the time mechanical harvesting was adopted in NSW, the large capacity chopper harvester was well established as the dominant design. The industry entered the harvesting arena with larger groups and high capacity equipment. Therefore, other regions such as Mackay may have been penalised for taking a lead in adoption of harvesting technology. The Mackay industry embraced mechanical harvesting unassisted by the benefits of hindsight.

4. Conclusions

Given the adjustment processes that have already taken place in other cane producing regions in Australia, the structure of the harvesting sector in the Mackay district has not changed as rapidly as might be expected. The historical basis of harvesting and transport systems in the sugar industry has been explored to identify key events in the evolution of harvesting systems which have impacted on the ability of the Mackay sugar industry to adjust to alternative harvesting systems, particularly the rationalised systems which now operate in most other cane producing regions.

Since mechanisation of the harvesting process, the Australian sugar industry has made ongoing organisational adjustments to incorporate new technology into harvesting and transport systems, but the dynamics of this process and the industry's adjustment response have been conditioned by important historical events.

This present paper presents a number of possible explanations for the slow rate at which cane harvesting and transport systems in Mackay were able to adapt and thereby realise potential economies of size, and the reasons why a wide range of harvesting machine vintages were still operating in that district. Despite the availability of harvester technology to harvest larger quantities of cane, a number of factors have acted against its efficient use.

Adjustment patterns were determined by arrangements in place before mechanical harvesting was introduced. The way in which adjustment patterns in Mackay stemmed from premechanical harvesting arrangements provides an example of nonergodicity – that is, noting Dosi and Orsenigo (1988), how a technological evolutionary path could be affected by small 'deviant' behaviour which became autocatalytic, progressively amplified and ultimately dominant. The available harvesting and transport technology, and the administrative arrangements set in place when the industry changed from manual cutting to a mechanised system, nurtured the continuation of small-group harvesting in Mackay. In more recent years, the interdependent nature of the components of the harvest-transport system, mill policies, and industry regulations has allowed the harvesting arrangements that originally developed in each cane producing region of Australia to become deeply entrenched over time Brennan (1999). The manner in which technological innovations have evolved has been a key feature in the development of complex, present-day mechanical harvesting systems.

Current harvesting systems are a result of path-dependent sequences. The preference for operating small groups in Mackay has a deeply rooted historical dimension and increasing returns to the use of familiar, small-group harvesting arrangements may be contrasted with the uncertain and often less attractive returns from changing to a larger group. These factors may have directed much of the Mackay harvest-transport sector into an organisational state that may have inferior long-run potential as far as cost efficiency is concerned.

The evolutionary economic concept of path dependency provides a useful framework to consider the development of harvesting systems, and the role of technology in shaping them. It is concluded that the dynamic process of incorporating new technology into harvesting systems, and the industry's response to technology has taken on an essentially historical character, much like the development of the QWERTY keyboard (David 1985).

Although diffusion studies of this nature in agriculture are not commonly reported, David (1985, p. 336) wrote 'outcomes of this kind are not so exotic. For such things to happen seems only too possible in the presence of strong technical interrelatedness, scale economies, and irreversibilities as a result of learning and habituation'. Hall (1994) noted that the process of innovation has a historical dimension absent from much formal economic analysis. Like much of the published literature from the evolutionary economics writers, the arguments presented in the present paper have not been formally modelled and contain a degree of speculation. However, as an attempt to broaden the application of evolutionary economic theories of innovation diffusion and technical change, it is hoped that this discussion has highlighted the historical importance of technical and institutional conditions in the analysis of adjustment processes.

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