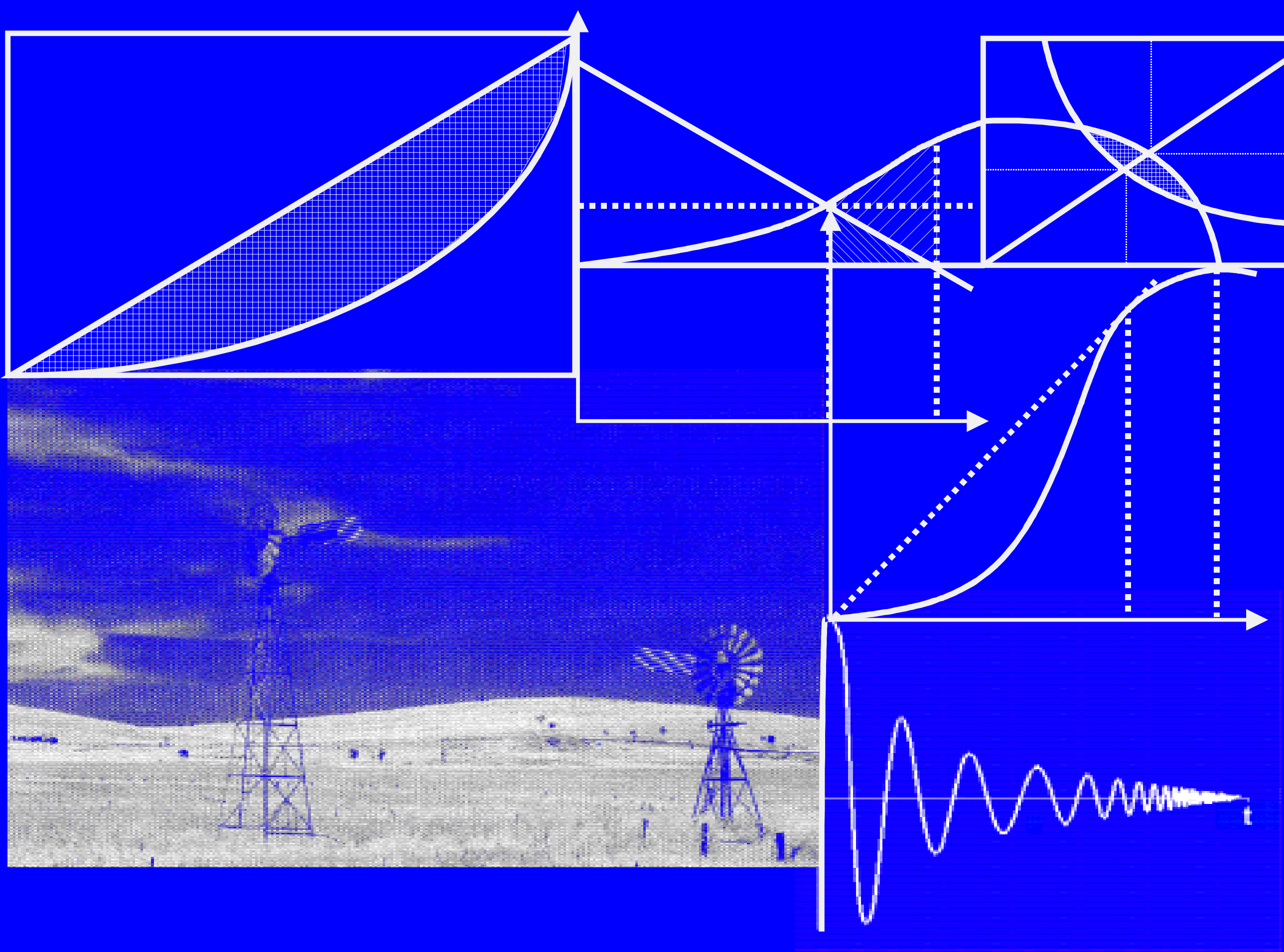
Agricultural and Natural Resource Economics Discussion Paper Series



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An Institutional Analysis of Partial Deregulation
of the Australian Wheat Industry
under Bertrand Competition

Agricultural Economics Discussion Paper 2/96

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Foreword

This project originated as an attempt to examine the impact of liberalization on the Australian Wheat Industry in the wake of the Hilmer reforms. In order to carry out such an analysis it quickly became clear that existing models of the Australian wheat industry, both partial and general equilibrium, did not sufficiently incorporate the institutional structure of the industry.

Partial analyses fail to capture general equilibrium effects, that is, they don't take into account price equilibrating effects across markets and sectors. However, they have the advantage of being able to handle institutional aspects such as imperfect competition and market intermediaries.

Attempts within the literature on computable general equilibrium (CGE) modelling to incorporate imperfect competition have involved the use of ad-hoc pricing schemes such as the Lerner markup pricing rule. The CGE literature has failed to keep pace with the speed and sophistication of much of the theoretical literature on both general equilibrium with imperfect competition and general equilibrium with market intermediaries.

In this paper we have attempted to develop a numerical general equilibrium model that builds on the newer theoretical literature involving general equilibrium with imperfect competition and middlemen. We have attempted to do this in a way that makes the analysis and model construction accessible to those economists to whom this literature would have remained otherwise inaccessible.

A numerical general equilibrium model of the partial deregulation of the Wheat Industry that followed in the wake of the Hilmer competition reforms is presented. The model incorporates imperfect competition, in the form of Bertrand competition between the AWB (Australian Wheat Board) and grain traders, and transaction costs into a unified framework. The AWB is represented as a Stackelberg leader in its role as a regulatory agency. Matching of supply and demand for grain between the grain traders and the growers completes the model. A Welfare analysis is carried out and it is concluded that the present state of deregulation is of little benefit to industry stakeholders.

No senior authorship has been assigned. In the initial stages one can attribute the institutional analysis to Tim Purcell and in the initial stages the theoretical approach to Rodney Beard, numerical work was carried out by both. Both algebraic and numerical work was done using MAPLE V3 on a P120, 64MB RAM NT 4.0 Box.

Research was partially funded under the Peel Fellowship, University of Queensland (Tim Purcell). We would like to thank Colin Brown (Department of Agriculture, University of Queensland) and Simon Kam (Department of Economics, University of Queensland) for their comments.

Rodney Beard and Tim Purcell
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An Institutional Analysis of Partial Deregulation of the Australian Wheat Industry under Bertrand Competition*

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Abstract

In this paper a numerical general equilibrium model of the partial deregulation of the Australian wheat industry that followed in the wake of the Hilmer competition reforms is presented. The model incorporates imperfect competition, in the form of Bertrand competition between the AWB and grain traders, and transaction costs into a unified framework. The AWB is represented as a Stackelberg leader in its role as a regulatory agency. Matching of supply and demand for grain between the grain traders and the growers completes the model. A welfare analysis is carried out and it is concluded that the present state of deregulation is of little benefit to industry stakeholders.

JEL Classification: C72, C78, D23, D43, D58

* No senior authorship assigned. Research partially funded under the Peel Fellowship, University of Queensland. We would like to thank Colin Brown (Department of Agriculture) and Simon Kam (Department of Economics) for their helpful comments.

1. Introduction

The implementation of the Hilmer Competition Policy recommendations in the Australian wheat industry has led to a growing debate about what is the best institutional structure for the wheat industry. The Grains Council of Australia through its Grains 2000 project has canvassed opinion from all sectors of the industry to try and formulate a institutional policy and framework that will benefit all in the industry. Despite extensive consultation and the commissioning of independent reports exploring the options for deregulation the industry has yet to fully explore the industry-wide implications for deregulation from a theoretical perspective.

The approach presented here involves an attempt to capture the institutional idiosyncrasies of the Australian wheat industry. In doing so we have allowed for both product differentiation on both international and domestic markets and price discrimination between the international and the domestic market. The incorporation of market intermediaries in the form of the Australian Wheat Board (AWB) and grain traders leads to a model with transactions costs. A numerical general equilibrium model is developed that differs from the usual models in that an Arrow-Debreu framework is not used. Instead a model that has characteristics of both models involving general equilibrium with imperfect competition, such as Negishi [14] and Marschak and Selten [11] as well as market intermediaries and transaction costs is presented [8, 10].

Since the inception of the Hilmer reforms the Australian wheat industry has become characterised by two types of market intermediaries - the AWB and grain traders The role of these intermediaries in the industry can be summarised by what Spulber [23, 24] calls *market-making behaviour*. Growers on the other hand are characterised by *market-taking* behaviour. Market-making firms are price setters not price takers and face costs of price adjustment known as menu costs. Market-takers on the other hand are also price takers. According to Spulber [22] the function of market-making intermediaries is to coordinate trade between consumers and market-taking firms. The function of the AWB and grain traders is therefore that of coordinating trade between growers and the international and domestic consumers. How well this is done is difficult to determine.

Numerical and computable general equilibrium models of the Arrow-Debreu type have proved useful as policy evaluation instruments in a wide range of applications. They have, however, some limitations, not the least of which is that they do not reflect the institutional structure of the real economy in any meaningful way. The real economy is characterised by differentiated products, price setting behaviour, increasing returns, market intermediaries and transaction costs.

The development of general equilibrium models that incorporate some of these features has been fraught with theoretical and conceptual difficulties. This has meant that the development of numerical and computable general equilibrium models with imperfect competition and transaction costs has lagged far behind the development of these models for Arrow-Debreu economies. Realistic policy evaluation will, however, eventually require the development of such models.

A number of approaches to pricing have been attempted in those few numerical and computable general equilibrium models that have attempted to incorporate imperfect competition.

A common approach has been to use some mark-up pricing rule (such as the Lerner Rule). This, however, although being a simple approach, is somewhat ad-hoc because is not founded on rational decision-making [13, pp. 151-152.]. Other approaches include contestable markets and Cournot competition [16, 17]. In the latter case a common technique is to make use of conjectural variations to simplify the model. This approach also suffers from the critique that it is somewhat ad-hoc in nature [7, p.214.] Another approach has been to use a focal pricing rule in which domestic prices are marked-up from the world market prices, i.e. domestic price equals world market price plus a tariff [7, p.214.].

Some attempts have been made to incorporate Bertrand competition into numerical and computable general equilibrium models but these involve competitor prices being assumed to be fixed and do not involve an explicit solution of the Bertrand game [7, p.214.].

The impression given by much of this literature is that in order to incorporate imperfect competition and product differentiation into numerical and computable general equilibrium models, ad-hoc adjustments to perfectly competitive Arrow-Debreu models need to be carried out [9] which may not be appropriate [15, p. 726].

In this paper we take a different approach. A numerical general equilibrium with imperfect competition of Bertrand type that also includes market intermediaries and transactions costs is developed from first principles. The AWB's regulatory function is incorporated via Stackelberg play between the board and growers, with the board being Stackelberg leader. Bertrand competition between the board and grain traders on the domestic retail market and a Nash matching equilibrium[6, 19] between grain traders and growers completes the model. The resultant system of equations is then solved numerically for an equilibrium system of prices.

This work is still at the preliminary stage and the results of the work therefore need to be interpreted with caution. Nevertheless, we feel that better policy information requires the development of such models. Ad-hoc solutions to the incorporation of numerical and computable general equilibrium models have tended to ignore the more recent theoretical literature on imperfect competition [3]. In particular, significant breakthroughs have been made in macroeconomic models with micro-foundations that incorporate imperfect competition [2]. We have in part drawn on this approach in this paper.

The rest of the paper is orgainised as follows: In section 2 we give an overview of the historical and institutional background of the Australian wheat industry[1]. In section 3 we present a Stackelberg price-quantity game of regulated trade between the board and growers. In section 4 we give an overview of the 1983-1989 reforms of the industry and the options for further microeconomic reform. In section 5 we generalise the Stackelberg price-quantity game to a Bertrand model of deregulation involving three types of agents. The first type are growers or producers. The other two types are market intermediaries of these one of the market intermediary sub-types includes only a single agent: the board. In section 6 we estimate prices for the deregulated model in a general equilibrium framework. Finally, in section 7, we draw policy conclusions and suggest some ways in which the model may be extended.

2. The role of a regulatory body in regulating competition: The case of the Australian Wheat Board

The formation of the AWB as a statutory marketing authority preceeded a period of low prices and instability in the market for wheat. The board was formed in 1948 in an attempt to impose some order and stability to the wheat industry and guarantee grower prices and ensure the supply of wheat to consumers. The board had full control over the acquisition, distribution and marketing of the wheat harvest. Growers were obliged to deliver all wheat to the board and receive as payment a weighted average of domestic and international sales less any levies imposed and freight, handling and administration charges.

When the board was formed a cost of production index was established to determine the home consumption price (HCP) for wheat and a guaranteed export price tied to the HCP. At various times in the first stabilisation scheme (1948/49 - 1952/53) up to four price systems were prevailing impacting on the returns to growers: the guaranteed minimum price, the actual export price on the free world market, the feed wheat price, and the International Wheat Council (I.W.C.) 1949 International Wheat Agreement (I.W.A.) price (See Figure 2.1).

[1] This section highlights the aspects of the AWB's institutional structure relevant to our model. For more complete histories of the Australian wheat industry see, for example, [5] and [18]

The tying of the HCP to the cost of production caused some resentment amongst growers, due to the prevailing world price being far above that of the HCP. The second stabilisation scheme (1953/54 - 1957/58) saw HCP's being tied to the prevailing I.W.C. price, or export prices in the absence of a I.W.A. rather than the cost of production.

Rising costs of production and falling world prices lead to the reintroduction of the cost of production being the determinate of the HCP in the third stabilisation scheme (1958/59 - 1962/63). With wildly fluctuating international prices in the 1960s and '70s domestic prices being tied to costs of production reduced grower incentives when world prices were high and increased incentives when world prices and demand was low. The overproduction of wheat in periods of low world demand and prices prompted the imposition of wheat delivery quotas beginning in 1969/70. By the fifth stablisation scheme (1968/69 - 1972/73) the guaranteed minimum price was set relative to world market prices and not tied to the cost of production as rising land values had inflated the cost of production fuelling increases in supply of wheat. Over the next two schemes (1974/75 - 1978/79, 1979/1980 - 1983/84) the domestic price formula was successively modified to equate domestic prices with costs and international prices and to decouple the HCP from the guaranteed minimum price.

In response to grower concerns about the large differential between domestic and international prices (See Figure 2.2) and the price pooling formula of the board, in 1983 the government took the first step to deregulation of the industry. This set the scene for the gradual removal of the board's statutory marketing authority powers on the domestic market. Growers for the first time were allowed to seek contracts elsewhere for domestic wheat but the board still retained single desk seller status on the international market.

3. General equilibrium in a regulated market

Consider the situation prior to the 1983 reforms of the Australian wheat industry. Under the statutory marketing authority powers of the AWB growers were obliged to deliver all wheat to the board. The board then distributed the wheat to the domestic and international retail markets before redistributing the proceeds of the sales back to the growers (See Figure 3.1).

In this section we formulate a model of regulation incorporating consumer demands and grower responses to those demands. We then derive the reaction curves of the various agents in the industry, growers, consumers and the board, before specifying a general equilibrium model of the institutional structure of the industry.

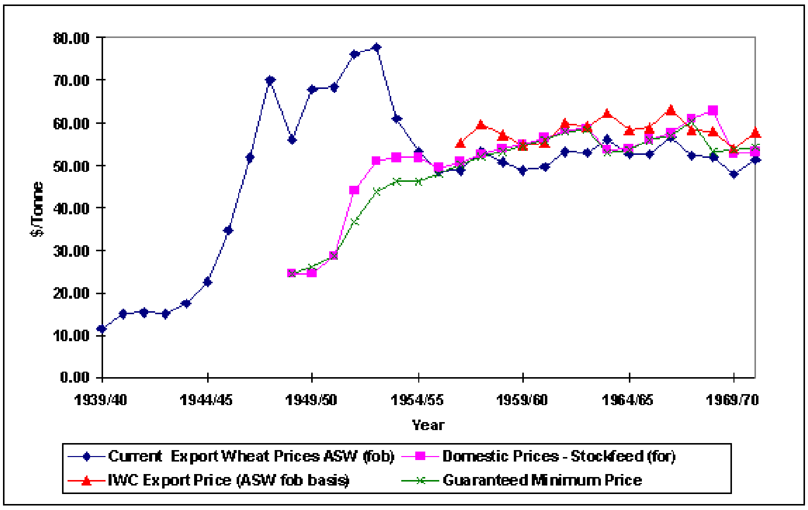

Figure 2.1: Pricing systems impacting on grower returns [1]

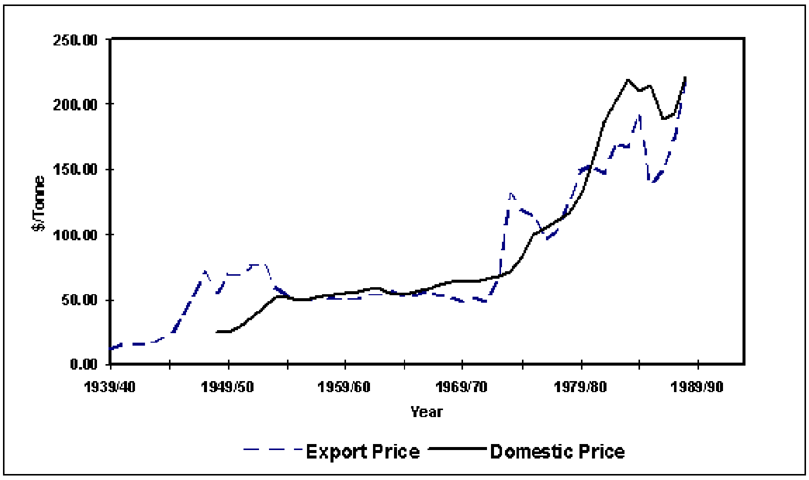

Figure 2.2: Human and Industrial domestic prices and ASW export prices [1]

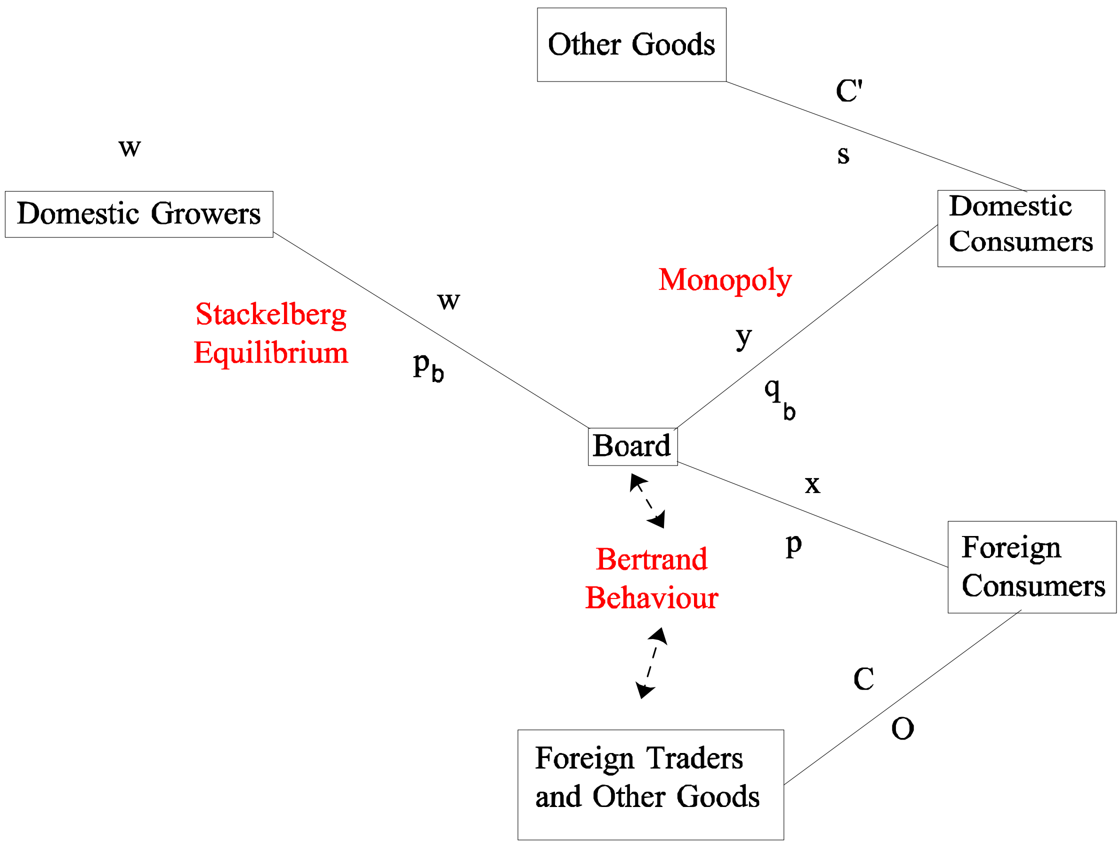

Figure 3.1: Institutional structure of the Australian wheat industry under regulation

3.1. The consumer's decision

We postulate the existence of two representative consumers, an international and domestic consumer. The consumers choose between purchasing wheat and an other composite good, which includes foreign sources of wheat in the case of the international consumer. In the case of the international consumer there exists a Bertrand-like behaviour between the Australian Wheat Board and foreign middlemen via the consumer which is not explicitly modelled.

3.1.1. The international consumer

The international consumer maximises a Cobb-Douglas utility function

$$\max_{x,C} U(x,C) = ax^{\alpha}C^{(1-\alpha)}$$

where x is the quantity of Australian wheat sold to the international consumer, C is a composite good including other wheat sold by foreign traders to the international consumers and α is the elasticity of substitution. This is subject to the budget constraint

$$px + OC = b$$

where p is the price of Australian wheat sold on the international market, O is the price of the composite good, and b is the international consumer's budget.

The lagrangian is of the form

$$L(x,C,\lambda) = ax^{\alpha}C^{(1-\alpha)} + \lambda\left[b - px - OC\right]$$

The first order conditions for this are

$$\frac{\partial L}{\partial x} = \frac{ax^{\alpha}\alpha C^{(1-\alpha)}}{x} - \lambda p = 0$$

$$\frac{\partial L}{\partial C} = \frac{ax^{\alpha}(1-\alpha)C^{(1-\alpha)}}{C} - \lambda O = 0$$

$$\frac{\partial L}{\partial \lambda} = b - px - OC = 0$$

Solving for λ and then for O we obtain the international demand for Australian wheat.

$$x^{*} = \frac{b\alpha}{p}$$

and the demand for the composite other good

$$C^{*} = \frac{b(1-\alpha)}{O}$$

3.1.2. The domestic consumer

The domestic consumer maximises a Cobb-Douglas utility function

$$\max_{y,C'} U\left(y, C'\right) = cy^{\beta} C'^{(1-\beta)}$$

where y is the quantity of wheat purchased by the domestic consumer, C' is a composite other good purchased by the consumers and β, is the elasticity of substitution. This is subject to the budget constraint

$$q_b y + sC' = d$$

where q_b is the price of wheat sold to the domestic consumer, s is the price of the composite other good and d is the domestic consumer's budget.

The lagrangian is of the form

$$L\left(y, C', \lambda\right) = cy^{\beta} C'^{(1-\beta)} + \lambda \left[d - q_b y - sC'\right]$$

The first order conditions for this are

$$\frac{\partial L}{\partial y} = \frac{c\beta y^{\beta} C'^{(1-\beta)}}{y} - \lambda q_b = 0$$

$$\frac{\partial L}{\partial C'} = \frac{cy^{\beta}\left(1-\beta\right) C'^{(1-\beta)}}{C'} - \lambda s = 0$$

$$\frac{\partial L}{\partial \lambda} = d - q_b y - sC' = 0$$

evaluating for $\frac{\partial L}{\partial \lambda} = 0$ we obtain the optimal demand for wheat and the composite other good

$$y^{*} = \frac{d\beta}{q_b}$$

and

$$C'^{*} = -\frac{d\left(\beta - 1\right)}{s}$$

3.2. The grower's decision

Prior to deregulation the board had compulsory acquisition of all wheat produced and paid a weighted average of the domestic revenue and export revenue from its sales of wheat. Growers attempted to maximise profits subject to the "pool" price that was set by the board. By setting the purchase price for wheat the board thus influenced growers decisions as growers then made production decisions based on the "pool" price. The board was thus a "leader" and the farmers "followers" in a Stackelberg game.

The weighted average or pool price p_b is defined as

$$p_b = \frac{px^* + q_b y^*}{x^* + y^*}$$

The objective function of the wheatgrower is given by

$$\max_w \prod = p_b w - e w^\delta$$

where w is the quantity of wheat produced and ew^δ is the cost of producing wheat with δ being the economies of scale associated with production.

The first order condition for this is

$$\frac{\partial \prod}{\partial w} = p_b - \delta e w^{(\delta - 1)} = 0$$

From this we obtain the optimal response of the grower

$$w^* = \left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}} = \left(\frac{(b\alpha + d\beta)\, p q_b \delta e}{b\alpha q_b + d\beta p}\right)^{\frac{1}{\delta-1}}$$

3.3. The board's decision

The board's role has changed over time through the different stabilisation plans. In the initial stabilisation plans after World War II and through the period of rationing the board's role was to deliver wheat at a low price to consumers by setting the home consumption price equal to the grower's cost of production. As international circumstances changed and the food security issue stabilised the board's remit changed to one of maximising grower returns by obtaining the highest possible prices. In the model the board takes into consideration the domestic and international demand for Australian wheat and sets its prices accordingly. The international market place is characterised by monopolistic or oligopolistic competition whereas the board acts as a monopolist in the domestic retail market.

As a monopolist, the board needs to choose its prices to maximise its profit

$$\max_{p,q_b} \prod = px^* + q_b y^* - p_b w^* - C_p p^{\phi} - C_q q^{\varphi}$$

where $C_p p^{\phi} + C_q q^{\varphi}$ are transaction costs of changing prices (menu costs). The menu costs can be seen as analogous to administration costs but on a per $ basis rather than on a per tonne basis as is usually reported. Since the board's remit is to return all revenue to the grower we can see that $p_b w^* = px^* + q_b y^*$. Further, the board in its role as a statutory marketing authority acts as a middleman in the marketing of the growers' harvest and attempts to maximise returns to growers by keeping its costs as low as possible.

In such a framework, the objective function of the wheat marketing board is given by

$$\min_{p,q_b} \prod = C_p p^{\phi} + C_q q^{\varphi}$$

subject to a materials balance constraint that the board cannot sell more than it purchases from the growers.

$$x^* + y^* \leq w^*$$

The lagrangian for the wheat board's decision problem is

$$\max_{p,q_b,\varepsilon} L\left(p, q_b, \varepsilon\right) = C_p p^{\phi} + C_{q_b} q_b^{\varphi} + \varepsilon \left[w^* - x^* - y^*\right]$$

The first order conditions are

$$\frac{\partial L}{\partial p} = C_p \phi p^{(\phi-1)} + \varepsilon \left[\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x^*}{\partial p}\right] = 0$$

$$\frac{\partial L}{\partial q_b} = C_{q_b} \varphi q_b^{(\varphi-1)} + \varepsilon \left[\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial q_b} - \frac{\partial y^*}{\partial q_b}\right] = 0$$

$$\frac{\partial L}{\partial \varepsilon} = w^* - x^* - y^*$$

Eliminating the lagrangian parameters we obtain a system of two equations.

$$\frac{C_{q_b} \varphi q_b^{(\varphi-1)}}{C_p \phi p^{(\phi-1)}} = \frac{\left[\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial q_b} - \frac{\partial y^*}{\partial q_b}\right]}{\left[\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x^*}{\partial p}\right]}$$

$$\frac{\partial L}{\partial \varepsilon} = w^* - x^* - y^* = 0$$

In other words the ratio of the marginal menu costs is equal to the ratio of the slopes of the supply and demand for wheat with a budget constraint.

Solving this system of equations (See Appendix D) we obtain

$$q_b^* = f(p, q_b)$$

$$p^* = f(p, q_b)$$

which are recursive (See Appendix A) and need to be solved numerically.

4. Modelling the Hilmer Competition Policy reforms

With the 1986-88 Royal Commission Inquiry into Grain Storage, Handling and Transport and the 1988 Industries Asssistance Commission Inquiry into the Wheat Industry there was an increasing awareness that

> ... the Australian grains industry would remain unprofitable and largely unsustainable while it continued to be producer-responsive, production-driven, merely trading and disposing of bulk undifferentiated commodities in a profoundly concentrated and corrupt world market.[5, p. 52]

As a result, it was realised that the only way forward was to reassess the institutional marketing arrangements and its associated pricing and incentives structure to make the industry more efficient and able to compete on the world market. The 1989 reforms to the Wheat Marketing Act removed the domestic monopoly of the board and enabled grain traders to compete against the board in the domestic market but there was considerable opposition from grower organisations to the removal of the single desk seller 'sacred cow'.

In 1993 the Hilmer National Competition Policy report was handed down which recommended that anti-competitive behaviour be limited and public monopolies be reformed. In terms of the wheat industry, this meant that the single desk seller status of the board and its trading on the domestic retail market were going to be under review. In response to pressure from the government and growers the Grains Council of Australia and the AWB embarked on a process of consultation and review of efficiency and competition in the industry.

In 1995 the industry commissioned a report into the board's single desk seller status and the viability of growers and traders in the industry. The main conclusions of the Booz, Allen and Hamilton consultant's report were that although the single desk seller status should be retained in the short to medium term as benefits to growers were in the order of $3/mt, with continued liberalisation of international agricultural trade, elimination of single desk seller status appears to be inevitable. The high administration costs of the board relative to similar sized international grain traders meant that in a fully deregulated market, with the board competing directly against traders, the board would not survive unless it owns or has a stake in handling and storage facilities. The report recommended that, in order to meet the challenges of the future, the AWB needed to corporatise with growers being principle shareholders. In conjunction with corporatisation the board needed capital assests and it was fundamental that Wheat Industry Fund (WIF) be continued to be collected to build up capital base [20].

The Grains 2000 Strategic Planning process in 1995 identified several options for continued reform of the wheat industry [21]:

Option 1 Reregulation

A return to compulsory acquisition of the harvest by the board.

Option 2 Deregulation

Full deregulation with the elimination of the board's single desk seller status.

Option 3 Do nothing

Keep the current, transition period, institutional structure of the industry where the board's single desk seller status was under constant review with government control of decision making.

Option 4 Single desk corporatisation

Retention of the single desk seller status in a government owned, grower represented, commercially orientated corporation.

Option 5 Single desk privatisation

Retention of the single desk seller status in a private company with growers as majority shareholders with the Wheat Industry Fund equity used as its capital base.

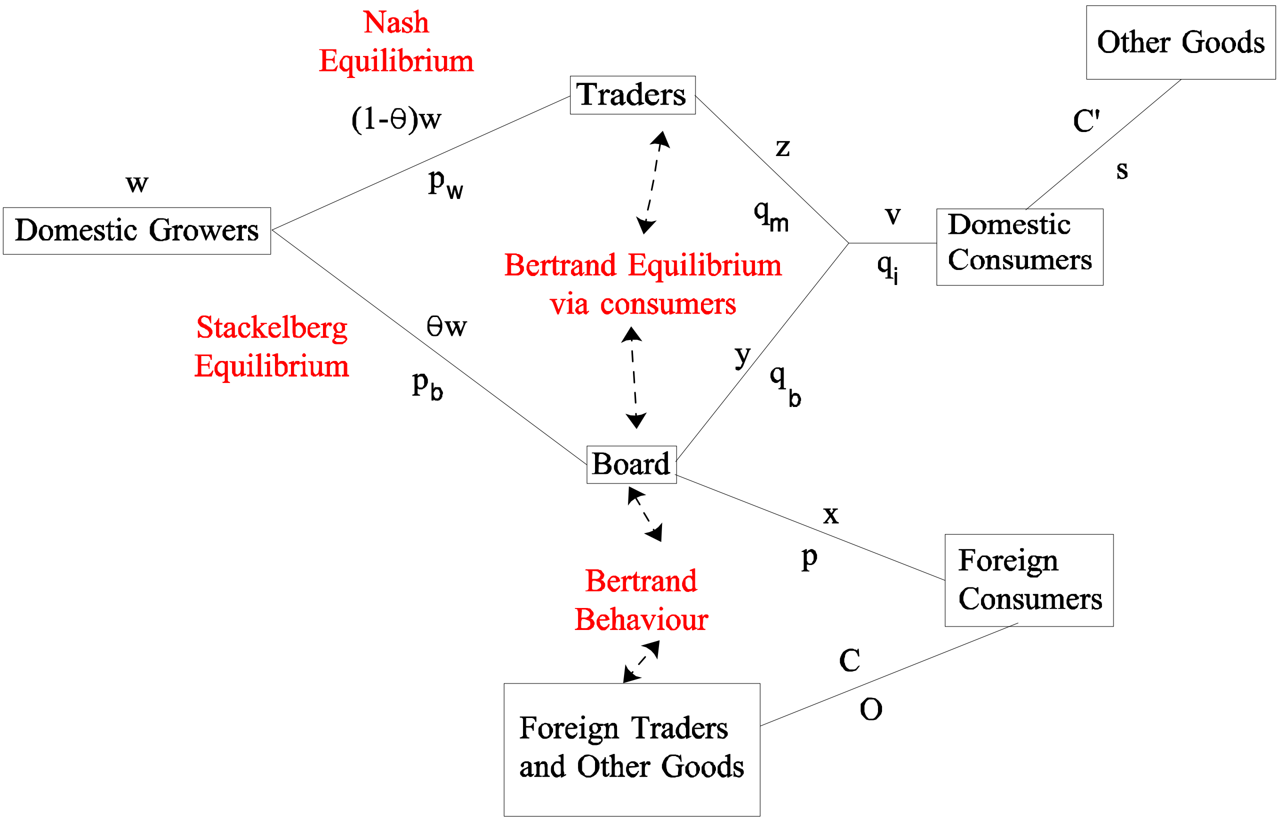

Figure 5.1: Institutional structure of the Australian wheat industry under deregulation

5. General equilibrium in a deregulated market

Consider the situation in which the Australian wheat industry were to deregulate but the board was still active as a single desk seller in the international market (Options 4 and 5). On the domestic market the board faces competition from middlemen who play a Bertrand game against the board (See Figure 5.1).

5.1. The consumer's decision

5.1.1. The international consumer

The international consumer's decision remains unchanged under the deregulation of the Australian wheat industry. The international consumer maximises a Cobb-

Douglas utility function

$$\max_{x,C} U(x,C) = ax^{\alpha}C^{(1-\alpha)}$$

where x is the quantity of Australian wheat sold to the international consumer, C is a composite other wheat sold by foreign traders to the international consumers and α is the elasticity of substitution.This is subject to the budget constraint

$$px + OC = b$$

where p is the price of Australian wheat sold on the international market, O is the price of the composite good, and b is the international consumer's budget.

The lagrangian is of the form

$$L(x, C, \lambda) = ax^{\alpha}C^{(1-\alpha)} + \lambda [b - px - OC]$$

The first order conditions for this are

$$\frac{\partial L}{\partial x} = \frac{ax^{\alpha}\alpha C^{(1-\alpha)}}{x} - \lambda p = 0$$

$$\frac{\partial L}{\partial C} = \frac{ax^{\alpha}(1-\alpha) C^{(1-\alpha)}}{C} - \lambda O = 0$$

$$\frac{\partial L}{\partial \lambda} = b - px - OC = 0$$

Solving for λ and then for O we obtain the international demand for Australian wheat.

$$x^{*} = \frac{b\alpha}{p}$$

and the demand for the composite other good

$$C^{*} = \frac{b(1-\alpha)}{O}$$

5.1.2. The domestic consumer

The domestic consumer's demand for wheat changes under the deregulation of the Australian wheat industry. Under deregulation the consumer now has a choice of supplier of wheat, the middlemen and the board. The quantity of wheat purchased by the consumer will be $v = f(y, z)$ where v is the quantity of wheat purchased by the domestic consumer comprising of wheat purchased from the board y and from the middlemen z. Under Bertrand competition [12, pp. 387-389] sales of wheat by the middlemen and the board are given by

$$v(q_b, q_m) = \begin{cases} v(q_b) & if\ q_b < q_m \\ \frac{1}{2}v(q_b) & if\ q_b = q_m \\ v(q_m) & if\ q_m < q_b \end{cases}$$

Since the consumer is indifferent between supplier for a particular quality of wheat at a particular price, if the price offered by the board, q_b, is lower that of the middlemen, q_m, the board will capture all of the market and the middlemen will sell no wheat $(v = y)$. If the prices are equivalent to each other, then the middlemen and the board will each supply half of the wheat to the market $\left(v = \frac{1}{2}y + \frac{1}{2}z\right)$.

The domestic consumer maximises a Cobb-Douglas utility function

$$\max_{v,C'} U(v, C') = cv^{\beta}C'^{(1-\beta)}$$

where C' is a composite other good and β is the elasticity of substitution. The elasticity of substitution is the same as the one in the regulated case as it's assumed that consumer preferences for wheat versus the composite other good does not change. This is subject to the budget constraint

$$q_i v + sC' = d$$

where q_i $(i = m, b)$, s is the price of the composite other good sold to the domestic consumer, and d is the domestic consumer's budget.

The lagrangian is of the form

$$L(v, C', \lambda) = cv^{\beta}C'^{(1-\beta)} + \lambda\left[d - q_i v - sC'\right]$$

The first order conditions for this are

$$\frac{\partial L}{\partial v} = \frac{c\beta v^{\beta}C'^{(1-\beta)}}{v} - \lambda q_i = 0$$

$$\frac{\partial L}{\partial C'} = \frac{cv^{\beta}(1-\beta)C'^{(1-\beta)}}{C'} - \lambda s = 0$$

$$\frac{\partial L}{\partial \lambda} = d - q_i v - sC' = 0$$

evaluating for $\frac{\partial L}{\partial \lambda} = 0$ we obtain

$$C'^* = \frac{d(1-\beta)}{s}$$

$$v^* = \frac{\beta d}{q_i}$$

this leads to three cases

Case 1 $q_b < q_m$

$$v^* = \frac{\beta d}{q_b}$$

Case 2 $q_b = q_m = q$

$$v^* = \frac{\beta d}{2q_b} + \frac{\beta d}{2q_m} = \frac{\beta d}{q}$$

Case 3 $q_b > q_m$

$$v^* = \frac{\beta d}{q_m}$$

5.2. The growers' decision

The growers receive payment for their produce from the traders and the board. The price paid by the traders for the grower's produce is defined as p_w whereas the board pays a weighted average of the domestic revenue and export revenue from its sales of wheat.

The weighted average or pool price p_b is defined as

$$p_b = \frac{px^* + q_i v^*}{x^* + v^*}$$

of which there are several cases, depending on v^*.

Case 1 $q_b < q_m$

$$p_b = \frac{px^* + \beta d}{x^* + \frac{\beta d}{q_b}}$$

Case 2 $q_b = q_m = q$

$$p_b = \frac{px^* + \frac{\beta d}{2}}{x^* + \frac{\beta d}{2q}}$$

Case 3 $q_b > q_m$

$$p_b = p$$

The objective function of the wheatgrower is given by

$$\max_{w} \prod = p_b \theta w + p_w (1 - \theta) w - ew^{\delta}$$

where θ is the market share of the grower's crop w sold to the wheat board and ew^{δ} is the cost of producing wheat with δ being the economies of scale associated with production.

The first order condition for this is

$$\frac{\partial \prod}{\partial w} = p_b \theta + p_w (1 - \theta) - \delta e w^{(\delta - 1)} = 0$$

From this we obtain the optimal response of the grower

$$w^* = \left(\frac{p_b \theta + p_w (1 - \theta)}{\delta e} \right)^{\frac{1}{\delta - 1}}$$

5.3. The board's decision

After deregulation the board faces competition from middlemen in the domestic retail market but continues to retain its monopoly on the export market. Rather than acquiring the full harvest it must also compete with the middlemen on the factor market. In such a framework the objective function of the board is given by

$$\max_{p, q_b} \prod = px^* + q_b y^* - p_b \theta w^* - C_p p^{\phi} - C_q q^{\varphi}$$

which, as in the regulated case, restricts down to

$$\min_{p, q_b} \prod = C_p p^{\phi} + C_{q_b} q_b^{\varphi}$$

subject to the constraint

$$x^* + v^* \leq \theta w^*$$

The lagrangian for the board's decision problem is

$$\min_{p,q,\varepsilon} L(p,q,\varepsilon) = C_p p^{\phi} + C_q q^{\varphi} + \varepsilon \left[\theta w^* - x^* - v^*\right]$$

The first order conditions are

$$\frac{\partial L}{\partial p} = C_p \phi p^{(\phi-1)} + \varepsilon \left[\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x}{\partial p}\right] = 0$$

$$\frac{\partial L}{\partial q} = C_q \varphi q^{(\varphi-1)} + \varepsilon \left[\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial q} - \frac{\partial v}{\partial q}\right] = 0$$

$$\frac{\partial L}{\partial \varepsilon} = \theta w^* - x^* - v^* = 0$$

Eliminating the lagrangian parameters we obtain a system of two equations.

$$\frac{C_q \varphi q^{(\varphi-1)}}{C_p \phi p^{(\phi-1)}} = \left(\frac{\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial q} - \frac{\partial v}{\partial q}}{\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x}{\partial p}}\right)$$

$$\theta w^* - x^* - v^* = 0$$

In other words the ratio of the marginal menu costs is equal to the ratio of the slope of the supply for wheat and the slope of the demand for wheat with a budget constraint.

This system is now evaluated for each of the Bertrand competition cases (See Appendices E and B).

Case 1 $q_b < q_m$

$$q_b = f(p, p_w, q_b)$$

$$p = g(p, p_w, q_b)$$

Case 2 $q_b = q_m = q$

$$q = f(p, p_w, q_b)$$

$$p = g(p, p_w, q)$$

These two systems are recursive in p, p_w and q_b and need to be solved numerically.

Case 3 $q_b > q_m$

In this case, the board does not compete on the domestic market and its sales are restricted to the export market. The objective function and thus the lagrangian change giving a system of two equations.

$$C_p \phi p^{(\phi-1)} + \varepsilon \left[\frac{\theta^2}{(\delta-1)\,\delta e} + \frac{b\alpha}{p^2} \right] = 0$$

$$\theta \left(\left(\frac{p\theta + p_w (1-\theta)}{\delta e} \right)^{\frac{1}{\delta-1}} \right) - \frac{b\alpha}{p} = 0$$

There is no closed form solution to this. The Board can only sell to the export market, and its decision to set its prices p and q are dependent on w^*, the reaction curve of the grower. Because domestic consumers prefer selling to the middlemen the growers will sell as much wheat to the middlemen first, until the domestic market is satisfied, and then sell the residual to the board at $p_b = p$. Thus the quantity sold to the middlemen depends on the consumers utility function with the residual of the harvest being sold to the board. The question of what price the board sets for p in this scenario is one that can only be answered with an extension of the model to include the international consumer and foreign traders in the Bertrand competition setting.

5.4. The middlemen's decision

Consider the problem faced by the deregulated sector, who choose

$$\max_{q_i, w} \prod = (1-S)\left(q_m v^* - p_w w (1-\theta) - k_{q_i} q_i^{\nu}\right)$$

subject to the constraint

$$v^* \leq (1-\theta)\, w$$

where $k_{q_i,}$ is the menu cost, S is the amount of profit repatriated by the middlemen to their parent company and the adjustment cost factor is ν

The lagrangian for the middlemen is

$$\max_{q_i, w, \zeta} L(q_i, w, \zeta) = (1-S)\left(q_i v^* - p_w w (1-\theta) - k_{q_i} q_i^{\nu}\right) - \zeta_i \left[(1-\theta)\, w - v^*\right]$$

giving

Case 1 $q_b < q_m$

$$\max_{q_m,w,\zeta} L(q_m, w, \zeta) = -(1-S)\left(p_w w(1-\theta) + k_{q_m} q_m^{\nu}\right) - \zeta_m\left[(1-\theta) w\right]$$

Case 2 $q_b = q_m = q$

$$\max_{q,w,\zeta} L(q, w, \zeta) = (1-S)\left(\frac{\beta d}{2} - p_w w(1-\theta) - k_q q^{\nu}\right) - \zeta\left[(1-\theta) w - \left(\frac{\beta d}{2q}\right)\right]$$

Case 3 $q_b > q_m$

$$\max_{q_m,w,\zeta} L(q_m, w, \zeta) = (1-S)\left(\beta d - p_w w(1-\theta) - k_{q_m} q_m^{\nu}\right) - \zeta_m\left[(1-\theta) w - \left(\frac{\beta d}{q_m}\right)\right]$$

The first order conditions for this are

Case 1 $q_b < q_m$

$$\frac{\partial L}{\partial q_m} = -(1-S)\left(\nu k_{q_m} q_m^{\nu-1}\right) = 0$$

$$\frac{\partial L}{\partial w} = -(1-S)\left(p_w(1-\theta)\right) - \zeta_m\left[(1-\theta)\right] = 0$$

$$\frac{\partial L}{\partial \zeta_m} = (1-\theta) w = 0$$

$$q_m^* = 0$$

$$\theta^* = 1$$

Case 2 $q_b = q_m = q$

$$\max_{q,w,\zeta} L(q, w, \zeta) = (1-S)\left(\frac{\beta d}{2} - p_w w(1-\theta) - k_q q^{\nu}\right) - \zeta\left[(1-\theta) w - \left(\frac{\beta d}{2q}\right)\right]$$

$$\frac{\partial L}{\partial q} = -\left(1-S\right)k_q \nu q^{\nu-1} - \zeta\left[\left(\frac{\beta d}{2q^2}\right)\right] = 0$$

$$\frac{\partial L}{\partial w} = -\left(1-S\right)p_w\left(1-\theta\right) - \zeta\left[\left(1-\theta\right)\right] = 0$$

$$\frac{\partial L}{\partial \zeta} = \left(1-\theta\right)w - \left(\frac{\beta d}{2q}\right) = 0$$

$$\zeta = -\left(1-S\right)p_w$$

$$w^* = \left(\frac{\beta d}{2\left(1-\theta\right)q}\right)$$

$$q^* = \left[\frac{\beta d p_w}{2k_q \nu}\right]^{\frac{1}{\nu+1}}$$

From this solution we can see that a Bertrand equilibrium will exist on the retail market and a Nash equilibrium will exist on the factor market.

Case 3 $q_b > q_m$

$$\frac{\partial L}{\partial q_m} = \left(1-S\right)k_{q_m}\nu q_m^{(\nu-1)} - \zeta\frac{\beta d}{q_m^2} = 0$$

$$\frac{\partial L}{\partial \zeta_m} = \left(1-\theta\right)w - \left(\frac{\beta d}{q_m}\right) = 0$$

$$\frac{\partial L}{\partial w} = -\left(1-S\right)p_w\left(1-\theta\right) + \zeta\left(\theta-1\right) = 0$$

$$\zeta = -\left(1-S\right)p_w$$

$$q_m^* = \left[-\frac{\beta d p_w}{k_{q_m}\nu}\right]^{\frac{1}{(\nu+1)}}$$

(which is undefined and thus we set $q_m^* = 0$) and also

$$w^* = \left(\frac{\beta d}{\left(1-\theta\right)q_m}\right)$$

From this solution we can determine that the equilibrium price sold to the domestic consumer by the middlemen, q_m^*,will only exist when the price offered to the growers by the middlemen, p_w, is zero.

6. Numerical Analysis

A general equilibrium in the deregulated case will in general exist only in the case where $q_m = q_b$. We need to solve the optimal decisions of the growers, middlemen and the board in order to obtain a general equilibrium solution. A solution of the model is given by the optimal prices (p^*, p_w^*, q^*). The general equilibrium model is outlined in Appendix C.

In order to numerically solve for the optimal prices (p_w^*, p^*, q^*) we first need to estimate the following equations econometrically to obtain estimates for elasticities of substitution (β, α) and budget totals (d, b)

$$x = b\alpha\frac{1}{p}$$

$$v = \beta d\frac{1}{q}$$

We econometrically estimate each of these equations using price and quantity data (AWB, various issues).

$$\hat{x} = \underset{(3.2^{**})}{1.14}\frac{1}{p}$$

$$\hat{v} = \underset{(9.18^{**})}{1.29}\frac{1}{q}$$

The wheat harvest parameters,(δ, e) and the middlemen's cost parameters, (k_q, ν) were chosen to obtain a solution. We have not calibrated the model against a benchmark equilibrium at this stage and the results should be interpreted with caution, however, the relative changes in prices and the corresponding welfare analysis are indicative of the direction of change, but not the magnitude.

The final equilibrium depends on θ . A series of equilibria may therefore be calculated for different θ values, for $0 < \theta < 1$. (See Tables 6.1 and 6.2).

We obtain multiple punctuated equilibria [4] for the optimal prices (shown in brackets) but only one equilibria exists when the board's market share reaches 70%. The only other market share level where there are multiple equilibria is at 80%. As it is unlikely that prices will jump, for example from $0.799, 0.774$, to

Table 6.1: Prices under deregulation

	Prices			
θ	p^*	q^*	p_w^*	p_b^*
0.9	0.799	3.165	4066.575	1.325
0.8	0.774 (15.022)	0.876 (16.998)	3680.187 (127.002)	0.825 (16.01)
0.7	N/A (21.384)	N/A (4.033)	N/A (335.882)	N/A (6.511)
0.4	-1.876	1.416	260.981	1.416
0.3	-1.661	1.477	181.327	1.477
0.2	-1.509	1.491	136.283	1.491
0.1	-1.393	1.487	107.501	1.487

Table 6.2: Growers welfare under deregulation

	Growers	
θ	w^*	$\prod$
0.9	20392.485	-4.15×10^{10}
0.8	36834.855 (1303.003)	-1.357×10^{11} (-1.357×10^{11})
0.7	N/A (5038.226)	N/A (-2.538×10^{9})
0.4	7857.744	-6.173×10^{9}
0.3	6368.614	-4.055×10^{9}
0.2	5466.212	-2.987×10^{9}
0.1	4844.973	-2.347×10^{9}

21.384 in the case of p^*, we conclude that the realistic equilibria at 80% and 70% market share of the board is at the second case. It is interesting to note that we obtain an equilibria at 70% market share, very close to the Booz Allen and Hamilton Consultant's report estimate of 66% [20].

It can be seen from the results that as the board's market share falls the international price, p^*, of Australian wheat that the board offers initially increases but eventually falls as the board is forced out of the domestic market. From the results in Table 6.1 it seems that the board, to remain viable in the domestic retail market in the face of falling factor market share, will have to either stop selling on the international market, or import wheat. This is shown by the negative prices as we have not incorporated net trade into the decision problem of the board. The results of the simulation imply that unless phytosanitary restrictions on imports are lifted the board will cease to exist on the international retail market. If phytosanitary restrictions are lifted the implications are that, firstly, the board will become an importer of wheat, by taking advantage of the higher domestic price relative to the international price. Secondly, the only way the Australian wheat industry can remain an exporter is to drop single desk selling status for the board allowing traders access to the export market.

The price offered to the growers by the middlemen, p_w^*, will fall as the middlemen gain market share. With p_w^* being higher than the domestic retail price, q^*, the middlemen are actually losing money (but at a diminishing rate as their market share increases) so long as the board remains an active player in the market. Again, this bears out the empirical evidence of the Booz Allen and Hamilton report.

Growers actually have a negative but increasing profitability as the market share of the board declines. This is a reflection of firstly, the large unit costs of harvesting used in the simulation to obtain an equilibria which may differ when the model is actually calibrated and secondly, due to the absence of alternative farm activities in the model such as wool production. As the market share of the board declines the board shifts out of supplying the international market with Australian wheat and the growers' return from the pool price is actually just their return from the domestic retail price, q^*[2]. The quantity of wheat produced declines as θ declines, implying that although grower profitability increases, there will be fewer growers to reap the benefits of deregulation.

7. Conclusion

In this paper we have developed a theoretical general equilibrium model of the partial deregulation of the Australian wheat industry. This model utilizes Bertrand competition to model imperfect competition and product differentiation in an explicit manner. In addition, it incorporates the role of grain traders and transactions costs in the domestic market after the Hilmer competition reforms. We have numerically parameterised the model based on empirical data and calculated an equilibrium set of prices.

Under deregulation there are only a few cases where there is existence of a general equilibrium. The middlemen cease to exist in the situation where the board's retail price is less than the middlemen's as consumers prefer to purchase wheat from the board under these circumstances. Where the middlemen charge a lower price than the board the existence of an equilibrium is dependent on the numerical values chosen in the optimal price offered. In general an equilibrium exists only where the retail prices offered by the board and the middlemen are identical and the consumers purchase equal quantities from each. This is consistent with results found in more simple models of Bertrand behaviour[12]

[2] This is actually not endogenised in the model and we have presented in the results the data that would have been obtained if this were so (i.e. the values for p_b^* when p^* becomes negative are set equal to q^* and the growers' production w^* and profit $\prod$ are recalculated).

In the reaction curves of the middlemen the critical variable in determining existence is the quantity of wheat purchased from the growers, w. In the board's optimisation problem the board takes into consideration the reaction curve of the growers, w^* when determining their optimal pricing structure whereas the middlemen don't. If the middlemen took into consideration w^* when determining their optimal pricing structure, existence of an equilibrium in the case where the middlemen's retail price is lower than that of the board would be guaranteed.

In summary, the institutional structure of the model, where middlemen do not have the necessary information to make correct decisions, leads to a situation where the middlemen can be forced from the market. In a general equilibrium although grain traders theoretically exist they make a loss. This may mean that they are forced from the market or it could be due to the fact that we have not yet calibrated the model against an empirical equilibrium. We model the institutional structure in this way as middlemen are new entrants to the market competing against an existing firm, the board. The board possesses detailed market knowledge (and grower representation on its governing board) and is thus in a better position to exercise market power. Interestingly, commentaries on the Booz Allen and Hamilton Consultant's report indicate that

> ... traders have moved out of milling wheat in response to what they see as unfair trading and market manipulation.
>
> [The report] reveals trader concerns that the AWB shares information between its trading division and its pool operations - something the AWB vigorously denies.
>
> Also of concern was a perception that commercially sensitive information was shared between the AWB and the bulk handling authorities and that the trade had unequal access to stock swaps.
>
> As a result of traders' reluctance to participate fully in the market, growers had not yet reaped the full benefits of domestic deregulation.[20]

The model shows that it's not necessary for the board to actively use its market power in order to induce middlemen to leave the market, as the institutional structure of the market itself leads to this position naturally.

The numerical results indicate that as the board loses market share, it progressively withdraws from active involvement in exports and concentrates on the more lucrative domestic market. Growers benefit through increased profits but overall the size of the sector, as measured by total harvest, diminishes. Consumers appear largely unaffected by these developments as wheat is only a small proportion of their total consumption.

We conclude from this that the present state of deregulation is of little benefit to anyone in the industry and that further deregulation, either the abolition of phytosanitary restrictions, with all its inherent dangers, and/or the scrapping of the single desk selling status of the board will be necessary for Australia to maintain its presence (either as an importer or exporter of wheat) in the international market. These conclusions should however be interpreted with caution as the welfare implications of full deregulation versus reregulation have not been explicitly analysed within the model presented in this paper.

Options for further model development include:

1. The incorporation of net foreign trade into the boards price setting decisions, to analyse the implications of single desk selling status versus full deregulation and reregulation fully.

2. Calibration and validation of the model for an equilibrium set of prices.

3. The incorporation of an analysis of competition in the international market into the model through the introduction of other grain trading nations into the model.

4. Expansion of the model to analyse the impact of deregulation at the state level within Australia.

5. The decoupling of growers' decisions from the board's optimisation function (w rather than w^*) which will eliminate the Stackelberg game played between the growers and the board. This will explore the privatisation of the board option[3] which removes the asymmetric information advantage the board holds over the other traders in the market.

Further research and development of the model presented here is probably necessary before the policy implications of the model can be interpreted with confidence.

[3] Option 5 of the Grains Council of Australia Strategic Planning process (See section 4).

A. Regulated Case Solutions

$$q_b^* = \frac{(1-\delta)\, d\beta p}{p\left(\frac{(b\alpha + d\beta) p q_b \delta e}{b\alpha q_b + d\beta p}\right)^{\frac{1}{\delta-1}} + b\alpha\,(\delta - 1)}$$

$$p^* = \frac{b\alpha}{\left(\frac{(b\alpha + d\beta) p q_b^* \delta e}{b\alpha q_b^* + d\beta p}\right)^{\frac{1}{\delta-1}} - \frac{d\beta}{q_b^*}}$$

B. Deregulated Case Solutions

Case 1 $q_b < q_m$

$$q_b^* = \frac{\begin{array}{c} d\beta p\left(p\theta\,(b\alpha + d\beta) + 2p_w b\alpha\,(1-\theta)\right)(\delta - 1) \\ \pm\sqrt{\begin{array}{c} \left((\theta - 1)(\delta - 1)(2d\beta p\theta)^2 (b\alpha + d\beta)^2 p^2 p_w\right)\left(\frac{\frac{(b\alpha + \beta d) p q_b}{b\alpha q_b + \beta d p}\theta + p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} \\ + (1-\delta)^2 p^2 (p\theta d\beta)^2 (b\alpha + d\beta)^2 \\ + (1-\theta)\left(\delta^2 - 3\delta + 2\right)(b\alpha + d\beta)(2pd\beta)^2\,\theta b\alpha p p_w \end{array}} \end{array}}{2\left(\begin{array}{c} \left(\left(\frac{\frac{(b\alpha + \beta d) p q_b}{b\alpha q_b + \beta d p}\theta + p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} p\theta\,(b\alpha + \beta d) + b\alpha\right) p\theta\,(b\alpha + d\beta) \\ + p_w b^2 \alpha^2 (1-\theta)(\delta - 1) \end{array}\right)}$$

$$p^* = \frac{b\alpha}{\theta\left(\frac{\frac{\theta(b\alpha + \beta d) p q_b}{b\alpha q_b + \beta d p} + p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} - \frac{\beta d}{q_b^*}}$$

Case 2 $q_b = q_m = q$

$$q^* = \frac{\begin{array}{c}(\delta-1)(2b\alpha+d\beta)\theta d\beta p^2 + (\theta-1)2^2 b\alpha d\beta p p_w \\ \pm\sqrt{\begin{array}{c}(\theta-1)(2b\alpha+\beta d)(2p\beta d\theta)^2 p^2 p_w\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} \\ +(2pd\beta\theta)^2 p^2 b\alpha\left(b\alpha(1-\delta)^2+d\beta(1+\delta)^2\right) \\ +(1-\delta)(1-\theta)(2b\alpha+d\beta)(2pd\beta)^2 2^2\theta b\alpha p p_w \\ +(1-\theta)^2(2\,pd\beta p_w b\alpha)^2 2^3+(1-\delta)^2(pd\beta\theta)^2(pd\beta)^2\end{array}}\end{array}}{\begin{array}{c}2(2b\alpha+d\beta)(p\theta)^2\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}+2^2(\delta-1)(2b\alpha+d\beta)b\alpha p\theta \\ +2(\theta-1)(2b\alpha)^2 p_w\end{array}}$$

$$p^* = \frac{b\alpha}{\theta\left(\frac{\theta\frac{(2b\alpha+\beta d)pq^*}{2b\alpha q^*+\beta dp}+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}-\frac{\beta d}{q^*}}$$

Case 3 $q_b > q_m$

$$C_p\phi p^{(\phi-1)}+\varepsilon\left[\frac{\theta^2}{(\delta-1)\delta e}+\frac{b\alpha}{p^2}\right]=0$$

$$\theta\left(\left(\frac{p\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\right)-\frac{b\alpha}{p}=0$$

C. Deregulated Case General Equilibrium Model

$$q^* = \frac{\begin{array}{c}(\delta-1)(2b\alpha+d\beta)\theta d\beta p^2 + (\theta-1)2^2 b\alpha d\beta p p_w \\ \pm\sqrt{\begin{array}{c}(\theta-1)(2b\alpha+\beta d)(2p\beta d\theta)^2 p^2 p_w\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} \\ +(2pd\beta\theta)^2 p^2 b\alpha\left(b\alpha(1-\delta)^2+d\beta(1+\delta)^2\right) \\ +(1-\delta)(1-\theta)(2b\alpha+d\beta)(2pd\beta)^2 2^2\theta b\alpha p p_w \\ +(1-\theta)^2(2\,pd\beta p_w b\alpha)^2 2^3+(1-\delta)^2(pd\beta\theta)^2(pd\beta)^2\end{array}}\end{array}}{\begin{array}{c}2(2b\alpha+d\beta)(p\theta)^2\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}+2^2(\delta-1)(2b\alpha+d\beta)b\alpha p\theta \\ +2(\theta-1)(2b\alpha)^2 p_w\end{array}} = \left[\frac{\beta d p_w}{2k_q\nu}\right]^{\frac{1}{\nu+1}}$$

$$p^* = \frac{b\alpha}{\theta\left(\frac{\theta\frac{(2b\alpha+\beta d)pq^*}{2b\alpha q^*+\beta dp}+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} - \frac{\beta d}{q^*}}$$

$$w^* = \left(\frac{p_b\theta + p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} = \left(\frac{\beta d}{2(1-\theta)q}\right)$$

D. Regulated Case partial differentiations

$$\frac{C_{q_b}\varphi q_b^{(\varphi-1)}}{C_p\phi p^{(\phi-1)}} = \left(\frac{\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial q_b} - \frac{\partial y^*}{\partial q_b}}{\frac{\partial w^*}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x^*}{\partial p}}\right)$$

$$w^* = \left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}$$

$$\frac{\partial w^*}{\partial p_b} = \frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}}{(\delta-1)p_b}$$

$$y^* = \frac{d\beta}{q_b}$$

$$\frac{\partial y^*}{\partial q_b} = -\frac{d\beta}{q_b^2}$$

$$x^* = \frac{b\alpha}{p}$$

$$\frac{\partial x^*}{\partial p} = -\frac{b\alpha}{p^2}$$

$$p_b = \frac{b\alpha + d\beta}{\frac{b\alpha}{p} + \frac{d\beta}{q_b}} = \frac{(b\alpha + d\beta)pq_b}{b\alpha q_b + d\beta p}$$

$$\frac{\partial p_b}{\partial q_b} = \frac{(b\alpha + d\beta)\, p^2 d\beta}{(b\alpha q_b + d\beta p)^2}$$

$$\frac{\partial p_b}{\partial p} = \frac{(b\alpha + d\beta)\, q_b^2 b\alpha}{(b\alpha q_b + d\beta p)^2}$$

$$\frac{C_{q_b}\varphi q_b^{(\varphi-1)}}{C_p\phi p^{(\phi-1)}} = \left(\frac{\left(\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}}{(\delta-1)p_b}\right)\left(\frac{(b\alpha+d\beta)p^2 d\beta}{(b\alpha q_b+d\beta p)^2}\right) + \frac{d\beta}{q_b^2}}{\left(\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}}{(\delta-1)p_b}\right)\left(\frac{(b\alpha+d\beta)q_b^2 b\alpha}{(b\alpha q_b+d\beta p)^2}\right) + \frac{b\alpha}{p^2}} \right)$$

$$\frac{C_{q_b}\varphi q_b^{(\varphi-1)}}{C_p\phi p^{(\phi-1)}} = \left(\frac{\left(\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}(b\alpha q_b+d\beta p)(b\alpha+d\beta)p^2 d\beta}{(b\alpha q_b+d\beta p)^2(\delta-1)(b\alpha+d\beta)pq_b}\right) + \frac{d\beta}{q_b^2}}{\left(\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}(b\alpha q_b+d\beta p)(b\alpha+d\beta)q_b^2 b\alpha}{(b\alpha q_b+d\beta p)^2(\delta-1)(b\alpha+d\beta)pq_b}\right) + \frac{b\alpha}{p^2}} \right)$$

$$\frac{C_{q_b}\varphi q_b^{(\varphi-1)}}{C_p\phi p^{(\phi-1)}} = \left(\frac{\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}} p d\beta}{(b\alpha q_b+d\beta p)(\delta-1)q_b} + \frac{d\beta}{q_b^2}}{\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}} q_b b\alpha}{(b\alpha q_b+d\beta p)(\delta-1)p} + \frac{b\alpha}{p^2}} \right)$$

$$\frac{\left(\frac{p_b}{\delta e}\right)^{\frac{1}{\delta-1}}(b\alpha q_b + d\beta p)(\delta-1)\, q_b^2 p^2}{(b\alpha q_b + d\beta p)^2 (\delta-1)^2 p q_b} = -\frac{b\alpha C_{q_b}\varphi q_b^{(\varphi+1)} - d\beta C_p \phi p^{(\phi+1)}}{\left(b\alpha C_{q_b}\varphi q_b^{(\varphi+1)} - d\beta C_p \phi p^{(\phi+1)}\right)}$$

$$\frac{\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}} q_b p}{(b\alpha q_b + d\beta p)(\delta-1)} = -1$$

$$q_b = \frac{-(b\alpha q_b + d\beta p)(\delta-1)}{p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}}$$

$$q_b = \frac{-b\alpha q_b(\delta-1) - (\delta-1)\, d\beta p}{p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}}$$

$$q_b + \frac{b\alpha q_b(\delta-1)}{p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}} = -\frac{(\delta-1)\, d\beta}{\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}}$$

$$\frac{q_b\left(p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}+b\alpha\left(\delta-1\right)\right)}{p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}}=-\frac{\left(\delta-1\right)d\beta}{\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}}$$

$$q_b=\frac{\left(1-\delta\right)d\beta p}{p\left(\frac{(b\alpha+d\beta)pq_b\delta e}{b\alpha q_b+d\beta p}\right)^{\frac{1}{\delta-1}}+b\alpha\left(\delta-1\right)}$$

E. Deregulated Case partial differentiations

Case 1 $q_b < q_m$

$$v^*=\frac{\beta d}{q_b}$$

$$\frac{\partial v^*}{\partial q_b}=-\frac{\beta d}{q_b^2}$$

$$x^*=\frac{b\alpha}{p}$$

$$\frac{\partial x^*}{\partial p}=-\frac{b\alpha}{p^2}$$

$$p_b=\frac{\left(b\alpha+\beta d\right)pq_b}{b\alpha q_b+\beta dp}$$

$$\frac{\partial p_b}{\partial q_b}=\frac{\left(b\alpha+\beta d\right)p^2\beta d}{\left(b\alpha q_b+\beta dp\right)^2}$$

$$\frac{\partial p_b}{\partial p}=\frac{\left(b\alpha+\beta d\right)q_b^2 b\alpha}{\left(b\alpha q_b+\beta dp\right)^2}$$

$$\frac{\partial w^*}{\partial p_b}=\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{\left(\delta-1\right)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)}$$

$$\frac{C_q\varphi q_b^{(\varphi-1)}}{C_p\phi p^{(\phi-1)}}=\left(\frac{\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)p^2\beta d}{(b\alpha q_b+\beta dp)^2}\right)+\frac{\beta d}{q_b^2}}{\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)q_b^2b\alpha}{(b\alpha q_b+\beta dp)^2}\right)+\frac{b\alpha}{p^2}}\right)$$

$$C_q\varphi q_b^{(\varphi-1)}\left(\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)\,q_b^2b\alpha}{(b\alpha q_b+\beta dp)^2}\right)+\frac{b\alpha}{p^2}\right)$$

$$=\left(\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)\,p^2\beta d}{(b\alpha q_b+\beta dp)^2}\right)+\frac{\beta d}{q_b^2}\right)C_p\phi p^{(\phi-1)}$$

$$\left(\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\frac{(b\alpha+\beta d)\,q_b^2b\alpha C_q\varphi q_b^{(\varphi-1)}}{(b\alpha q_b+\beta dp)^2}\right)+\frac{b\alpha C_q\varphi q_b^{(\varphi-1)}}{p^2}$$

$$=\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)\,p^2\beta dC_p\phi p^{(\phi-1)}}{(b\alpha q_b+\beta dp)^2}\right)+\frac{\beta dC_p\phi p^{(\phi-1)}}{q_b^2}$$

$$\frac{b\alpha C_q\varphi q_b^{(\varphi-1)}}{p^2}-\frac{\beta dC_p\phi p^{(\phi-1)}}{q_b^2}$$

$$=\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)\right)}\right)\left(\frac{(b\alpha+\beta d)\,\beta dC_p\phi p^{(\phi+1)}}{(b\alpha q_b+\beta dp)^2}-\frac{(b\alpha+\beta d)\,b\alpha C_q\varphi q_b^{(\varphi+1)}}{(b\alpha q_b+\beta dp)^2}\right)$$

$$\begin{aligned}&\frac{b\alpha C_q\varphi q_b^{(\varphi-1)}q_b^2-\beta dC_p\phi p^{(\phi-1)}p^2}{p^2q_b^2}\\ =\ &\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)}\right)\left(\frac{\left(b\alpha+\beta d\right)\beta dC_p\phi p^{(\phi+1)}-\left(b\alpha+\beta d\right)b\alpha C_q\varphi q_b^{(\varphi+1)}}{\left(b\alpha q_b+\beta dp\right)^2}\right)\end{aligned}$$

$$\begin{aligned}&\frac{b\alpha C_q\varphi q_b^{(\varphi+1)}-\beta dC_p\phi p^{(\phi+1)}}{p^2q_b^2}\\ =\ &\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)}\right)\left(\frac{\left(b\alpha+\beta d\right)\left(\beta dC_p\phi p^{(\phi+1)}-b\alpha C_q\varphi q_b^{(\varphi+1)}\right)}{\left(b\alpha q_b+\beta dp\right)^2}\right)\end{aligned}$$

$$\begin{aligned}&\frac{b\alpha C_q\varphi q_b^{(\varphi+1)}-\beta dC_p\phi p^{(\phi+1)}}{p^2q_b^2}\\ =\ &\theta\left(\frac{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)}\right)\left(\frac{\left(b\alpha+\beta d\right)\left(\beta dC_p\phi p^{(\phi+1)}-b\alpha C_q\varphi q_b^{(\varphi+1)}\right)}{\left(b\alpha q_b+\beta dp\right)^2}\right)\end{aligned}$$

$$p^2q_b^2=-\left(\frac{(\delta-1)\left(\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)\left(b\alpha q_b+\beta dp\right)^2}{\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta^2\left(b\alpha+\beta d\right)}\right)$$

$$\begin{aligned}&p^2q_b^2\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta^2\left(b\alpha+\beta d\right)\\ =\ &-\left(\delta-1\right)\left(\frac{\left(b\alpha+\beta d\right)pq_b}{b\alpha q_b+\beta dp}\theta+p_w\left(1-\theta\right)\right)\left(b\alpha q_b+\beta dp\right)^2\end{aligned}$$

$$q_b = \frac{d\beta p\left(p\theta\left(b\alpha+d\beta\right)+2p_w b\alpha\left(1-\theta\right)\right)\left(\delta-1\right) \pm \sqrt{\begin{array}{c}\left(\left(\theta-1\right)\left(\delta-1\right)\left(2d\beta p\theta\right)^2\left(b\alpha+d\beta\right)^2 p^2 p_w\right)\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} \\ +p^2\left(p\theta d\beta\right)^2\left(b\alpha+d\beta\right)^2\left(1-\delta\right)^2 \\ +\left(1-\theta\right)\left(\delta^2-3\delta+2\right)\left(b\alpha+d\beta\right)\left(2pd\beta\right)^2\theta b\alpha p p_w\end{array}}}{2\left(\begin{array}{c}\left(\left(\frac{\frac{(b\alpha+\beta d)pq_b}{b\alpha q_b+\beta dp}\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} p\theta\left(b\alpha+\beta d\right)+b\alpha\right)p\theta\left(b\alpha+d\beta\right) \\ +p_w b^2\alpha^2\left(1-\theta\right)\left(\delta-1\right)\end{array}\right)}$$

Case 2 $q_b = q_m = q$

$$v^* = \frac{\beta d}{2q}$$

$$\frac{\partial v^*}{\partial q} = -\frac{\beta d}{2q^2}$$

$$x^* = \frac{b\alpha}{p}$$

$$\frac{\partial x^*}{\partial p} = -\frac{b\alpha}{p^2}$$

$$\frac{\partial w^*}{\partial p_b} = \frac{\theta}{\left(\delta-1\right)\delta e}$$

$$p_b = \frac{b\alpha+\frac{\beta d}{2}}{\frac{b\alpha}{p}+\frac{\beta d}{2q}} = \frac{\left(2b\alpha+d\beta\right)pq}{2b\alpha q+d\beta p}$$

$$\frac{\partial w^*}{\partial p_b} = \frac{\left(\frac{\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}\theta}{\left(\delta-1\right)\left(\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta+p_w\left(1-\theta\right)\right)}$$

$$\frac{\partial p_b}{\partial q} = \frac{\left(2b\alpha+\beta d\right)\beta dp^2}{\left(2b\alpha q+\beta dp\right)^2}$$

$$\frac{\partial p_b}{\partial p} = 2\frac{(2b\alpha + \beta d)\, b\alpha q^2}{(2b\alpha q + \beta dp)^2}$$

$$\frac{C_q \varphi q^{(\varphi-1)}}{C_p \phi p^{(\phi-1)}} = \left(\frac{\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial q} - \frac{\partial v}{\partial q}}{\theta \frac{\partial w}{\partial p_b}\frac{\partial p_b}{\partial p} - \frac{\partial x}{\partial p}} \right)$$

$$\frac{C_q \varphi q^{(\varphi-1)}}{C_p \phi p^{(\phi-1)}} = \left(\frac{\theta \left(\frac{\left(\frac{\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)}{\delta e} \right)^{\frac{1}{\delta-1}} \theta}{(\delta-1)\left(\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)\right)} \right) \left(\frac{(2b\alpha+\beta d)\beta dp^2}{(2b\alpha q+\beta dp)^2}\right) + \frac{\beta d}{2q^2}}{\theta \left(\frac{\left(\frac{\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)}{\delta e} \right)^{\frac{1}{\delta-1}} \theta}{(\delta-1)\left(\left(\frac{(2b\alpha+d\beta)pq}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)\right)} \right) \left(2\frac{(2b\alpha+\beta d)b\alpha q^2}{(2b\alpha q+\beta dp)^2}\right) + \frac{b\alpha}{p^2}} \right)$$

$$\begin{aligned} & q^2 p^2 \left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)}{\delta e} \right)^{\frac{1}{\delta-1}} \theta^2 (2b\alpha + \beta d) \\ = \;& -(\delta-1)\left(\left(\frac{(2b\alpha + d\beta)\, pq_b}{2b\alpha q + d\beta p} \right)\theta + p_w(1-\theta) \right)(2b\alpha q + \beta dp)^2 \end{aligned}$$

$$\begin{aligned} & q^2 p^2 \left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta + p_w(1-\theta)}{\delta e} \right)^{\frac{1}{\delta-1}} \theta^2 (2b\alpha + \beta d) - 2b\alpha \left(\begin{array}{c} p\theta(1-\delta)(2b\alpha + d\beta) \\ +2b\alpha p_w(1-\theta) \end{array} \right) q^2 \\ & -pd\beta \left(\begin{array}{c} p\theta(1-\delta)(2b\alpha + d\beta) \\ +4p_w b\alpha(1-\theta) \end{array} \right) q + (d\beta p)^2 p_w (1-\theta) \\ = \;& 0 \end{aligned}$$

$$q_b = \frac{\begin{array}{c}(\delta-1)(2b\alpha+d\beta)\theta d\beta p^2+(\theta-1)2^2 b\alpha d\beta p p_w \\ \pm\sqrt{\begin{array}{c}(\theta-1)(2b\alpha+\beta d)(2p\beta d\theta)^2 p^2 p_w\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}} \\ +(2pd\beta\theta)^2 p^2 b\alpha\left(b\alpha(1-\delta)^2+d\beta(1+\delta)^2\right) \\ +(1-\delta)(1-\theta)(2b\alpha+d\beta)(2pd\beta)^2 2^2\theta b\alpha p p_w \\ +(1-\theta)^2(2\,pd\beta p_w b\alpha)^2 2^3+(1-\delta)^2(pd\beta\theta)^2(pd\beta)^2\end{array}}\end{array}}{\begin{array}{c}2(2b\alpha+d\beta)(p\theta)^2\left(\frac{\left(\frac{(2b\alpha+d\beta)pq_b}{2b\alpha q+d\beta p}\right)\theta+p_w(1-\theta)}{\delta e}\right)^{\frac{1}{\delta-1}}+2^2(\delta-1)(2b\alpha+d\beta)b\alpha p\theta \\ +2(\theta-1)(2b\alpha)^2 p_w\end{array}}$$

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