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Farmer-Entrepreneurs, Agricultural Innovation, and Explosive Research and Development Cycles

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Abstract: Private sector research and development (R&D) in food processing has seen a growing share of agricultural R&D. This paper analyzes market and technological links between farmer-entrepreneurs and food processing firms. It is shown that processing sector R&D tends to display explosive cycles. To avoid explosive cycles, the processing sector sets the R&D growth path and its target. Dynamic adjustments are related to the shadow price of R&D and farm output price. In equilibrium, the effects of increases in technological innovations (e.g., at the farm level, in public agricultural research, from entrepreneurial talent, in processing sector R&D, and in the price of final goods) on agricultural price and output are positive. The patent race does not affect steady-state agricultural price and output, nor processing sector R&D; it only reduces the opportunity cost of R&D.

Keywords: agricultural innovations; research and development cycles

1. Introduction

With the globalization and greater market integration that have been occurring in recent years, the rural economy is now more heavily influenced by farmer-entrepreneurs who are more responsive to shifts in market demand related to changes in preferences, fads, and fashions [1]. Put differently, farmer-entrepreneurs are more connected to supply chains, integrated in industry, and active in the creation of new networks compared with more traditional farmers. Thus, it is not surprising that research over the past two decades that discusses the sources of (and policies related to) agricultural wealth creation provide a number of strategies for developing the rural economy that are each aimed at generating entrepreneurial capacity [2–5], while also acknowledging that each strategy also depends on that entrepreneurial capacity [6–8]. According to a recent study, the farmer-entrepreneurs shaped by these strategies are more receptive to new technologies and assistance from extension, more attentive to changes in prices and the availability of credit, and less risk averse [9].

Within the modern rural economy described above, relatively little is known about how farmer-entrepreneurs' innovations relate to their industrial partners, such as those in the food processing sector, and to research and development (R&D). One view holds that, as farmer-entrepreneurs look for more efficient and profitable ways to produce, they are more open to innovation and the application of the innovation of their partners, such as when farmer-entrepreneurs seek greater integration with the food processing sector. These sectors of the economy markedly differ, however, in terms of market structure. Farmers are generally seen as price takers, while the food processing sector tends to be concentrated and non-competitive [10–12]. As such, it may be the case that increasing integration drives farmer-entrepreneurs to adapt technological innovations from the processing sector [13,14]. It may also be the case that agricultural innovation impacts technological innovations in the processing sector. Moreover, the interplay between innovations from both sectors is also affected by public policy and through basic agricultural research conducted within universities and research agencies. It is generally accepted that public agricultural research, by creating basic scientific knowledge, developing novel technologies, and facilitating diffusion and adoption of modern plant varieties and farming methods, has achieved remarkable success [15]. The literature, however, shows that these research gains in agriculture are not fully reflected in higher social welfare because they can be negatively impacted by market structure and a lack of competition in the downstream processing sector [16]. Thus, although much is known about today's rural economy, there is still more to learn.

This paper contributes to the currently underdeveloped theoretical literature in this area by presenting and analyzing a dynamic model of technological innovation and agricultural entrepreneurship [17]. The dynamic model presents two economic sectors—a non-competitive industrial sector (i.e., food processing), which is the leader, and an agricultural sector, which is considered to be the follower. The close integration of both sectors is a sign of entrepreneurism by farmers who are motivated to increase productivity and other margins [18]. We further examine the determinants of agricultural prices, output, and R&D in the processing sector. Given new research highlighting recent changes in the institutional structure of agricultural research [19], a better understanding of the relationship between farmer-entrepreneurs and R&D, such as that gained through the dynamic model developed in this study, is crucial.

The solutions from the formal model developed in this study display explosive cycles for R&D, wherein increases in processing sector R&D expenditures grow ever larger. In order to avoid these unstable paths, processing firms generate an optimal control model with stable solutions by setting the dynamic path of R&D and its target. Additionally, the formal model allows for study of the impact of patent races, agricultural research, entrepreneurial talent, and the pricing of final goods on processing sector R&D and agricultural prices and output. These aspects of the usefulness of our model in generating a greater understanding of the relationships between agricultural prices, processing sector R&D, public and private agricultural research, and final goods prices are supported by the presentation of U.S. data for the period 1994–2013, which indicate the predicted positive relationships between the first and final three of these variables.

2. Farmer-Entrepreneurs and Agricultural Innovation

Before turning to aspects of our dynamic model, we first discuss some of the attributes and activities of farmer-entrepreneurs. As stated previously, these market-oriented farmers are forward-looking and amenable to taking *calculated* risks, creating new products, adapting new technologies, and innovating in their use. As they pay more attention to the survival of their businesses in the long run, they are willing to make them more sustainable. As entrepreneurs, this new type of farmer is always looking for new opportunities to grow, improve, and expand his or her enterprise [20]. The relatively recent trend in agritourism represents one manifestation of this expansion. A new study indicates that agritourism involves attracting paying visitors to farms by offering farm tours, harvest festivals, hospitality services (e.g., bed and breakfast services), petting zoos, and other attractions [21]. Agritourism farms also typically produce agricultural commodities and a variety of other goods and services, engage in direct marketing of fresh foods to individual consumers and retailers, provide value-added agriculture (e.g., beef jerky, fruit jams, jelly, preserves, cider, wine, and floral arrangements), generate renewable energy, and engage in custom work (e.g., machine hire and hauling for other farms).

A recent study, using Census of Agriculture records and a propensity score matching technique to estimate the effects of agritourism on the net cash income per acre of New Jersey farms, finds that agritourism has statistically significant and positive effects on farm profitability, particularly in the case of small farms operated by individuals primarily engaged in farming [22]. Related research indicates that the likelihood of engaging in agritourism is significantly higher for farms employing organic production techniques and farm conservation practices [23]. Research also suggests that education and connections to the broader economy are associated with farmers' adoption of such activities, as 2012 Agricultural Resource Management Survey (ARMS) data indicates that farmer-entrepreneurs are more likely to have a college degree, use the Internet for business, and draw on paid management advice than are traditional farmers. These findings support research indicating that college-educated business owners are found to be more successful entrepreneurs than their counterparts who are not college educated [24–26].

Modern farmer-entrepreneurs are also amenable to the application of new technologies in farming practice. Data from the U.S. Department of Agriculture that is presented in Table 1 indicate that more than 90% of all corn, cotton, and soybean planted in 2016 is genetically engineered in some form. This compares to only 25–61% of these crops planted in 2000. Similarly, more than 75% of all corn and cotton planted in 2016 is of the stacked-gene variety, which involves a genetic process modern farmers use to combat the well-documented resistance of weeds to commercial herbicides. These percentages compare very favorably to their 2000 counterparts, which range from only 1–20% of all corn and cotton planted.

Table 1. Genetically engineered agriculture in the U.S., 2000–2016.

Year	Genetically Engineered Crop Production as % of Crop Planted			Stacked-Gene Variety Crop Production as % of Crop Planted	
	Corn	Cotton	Soybean	Corn	Cotton
2016	92	93	94	76	80
2000	25	61	54	1	20

Regular: U.S. Department of Agriculture.

Lastly, data gathered from the U.S. Patent and Trademark Office and presented in Table 2 suggest that technology innovations are of growing importance to modern farmer-entrepreneurs. Individual patenting activity in the areas of animal husbandry, fencing, fertilizers, harnesses for working animals, land vehicles, plant husbandry, and refrigeration was greater during the 1991–2010 period than during 1971–1990. In six of these seven areas, the increase (from 1971–1990 to 1991–2010) is statistically significant, while in none of the three areas in which individual patenting activity decreased (i.e., crop threshing/separating, harvesters and planting) is the change significant.

Table 2. Individually owned agriculture-related patents in the U.S., 1971–2010.

Technology Class	Patents Per Year	
	1991–2010	1971–1990
Animal Husbandry	188.45	115.30
Crop Threshing/Separating	5.05	5.10
Fences	28.40	22.10
Fertilizers	9.60	9.15
Harness for Working Animal	16.10	10.25
Harvesters	56.55	72.75
Land Vehicles	351.95	265.75
Plant Husbandry	81.55	59.20
Planting	18.35	19.25
Refrigeration	125.00	99.35

Regular: U.S. Patent and Trademark Office.

Beyond the advantages detailed above, there is also the view that an increase in agricultural entrepreneurship tends to increase all types of commerce and research, as well as the financial linkages between farmers and banks, processing firms, universities, and other agricultural research agencies. Additionally, it is expected that farmer-entrepreneurs contribute to and thus increase social capital [27], provided that they create new networks and social ties that facilitate cooperation and coordination for mutual benefit [28,29]. These points transition back to our formal model, which is presented in the next section of this paper.

3. The Variational Calculus Model

Prior research identifies innovative behavior in five dimensions: product and service innovation, market development, marketing methods, process technology and innovation, and the use of information technology in administration [30]. In this model, we study process technology and innovation at the farm level as well as at its main partner, the food processing firm, given that this dimension is most relevant in terms of interaction between these two entities. In our model, the farm sector is competitive and sells its product to a noncompetitive food processing sector. Given that the processing sector buys all farm produce, the relationship between the sectors is hierarchical. The processing sector is the leader and the farm sector is the follower. In this Stackelberg game, we first examine the farm sector, whose solution yields the reaction function that the processing sector takes into account in an effort to maximize its profits over time.

As a first step, we let Y denote farm output, S represent exogenous innovations in the farm sector, R denote research and development (R&D) in the processing sector, p represent the price paid for farm ouput, and f denote the farm sector production function, while noting that Y is also an input in the production of Y. The farmer-entrepreneur's problem is that of maximizing profits given technological and market ties with the processing sector. In this case, the farmer's profits are given by

$$pf(Y,R,S) - C(R,S)\,Y \tag{1}$$

where all arguments in the production and cost functions have positive marginal effects. The first order condition for Y is

$$pf_Y(Y,R,S) = C(R,S) \tag{2}$$

The marginal cost of producing the farm good decreases with S and R; here, $C_S(R,S) < 0$, and $C_R(R,S) < 0$, given that innovations reduce farm costs. Research and development in the processing sector can be a substitute ($C_{RS}(R,S) > 0$) for, or complement ($C_{RS}(R,S) < 0$) to, farm innovations. Next, the farm output determined by Equation (2) can be rewritten as a function of R, S and p:

$$Y = Y(R,S,p) \tag{3}$$

which can be derived from an equivalent formulation for farm profit, $pY - C(R,S,Y)$.

Omitting labor from the analysis, which is positively related to farm output Y, farm output Y grows with all arguments:

$$\frac{dY}{dp} = \frac{-f_Y}{pf_{YY}} > 0; \frac{dY}{dR} = \frac{C_R - pf_{YR}}{pf_{YY}} > 0; \frac{dY}{dS} = \frac{C_S - pf_{YS}}{pf_{YY}} > 0; \textit{ where } f_{YY} < 0; f_{YR}.f_{YS} > 0 \tag{3'}$$

The profit of the representative firm in the non-competitive food processing sector at any point in time corresponds to the difference between total revenue and the total costs of buying and processing farm output and developing processing technology. As such,

$$\pi = PF(Y(R,S,p)) - cR - \chi(\dot{R}) - pY(R,S,p) \tag{4}$$

where the first term of the right hand side (RHS) is total revenue from sales of the processing sector's final good, P is its price, and F is its production function. The second term on the RHS is the cost of cumulative R&D effort in the processing sector. The function $\chi(\dot{R})$ represents the net cost faced by the firm from adjusting the growth of cumulative R&D effort in order to develop new processing technology, where $\dot{R} \equiv dR/dt$ is the growth of cumulative R&D effort. The last term on the RHS is the cost of the agricultural product.

Applying the discount factor e^{-rt}, where $r > 0$ is the food processing sector firm's discount rate (i.e., its impatience), to this expression and summing over time, we can express the present value of the processing firm's profits as

$$W = \int_0^\infty [PF(Y(R,S,p)) - cR - \chi(\dot{R}) - pY(R,S,p)]e^{-rt}dt \tag{5}$$

subject to $R(0) = R_0$.

There are two state variables, p and R, in the objective function. As such, there are two Euler equations. The first Euler equation yields the optimal agricultural prices that the processing sector offers to farmer-entrepreneurs:

$$W_p - \frac{d}{dt}W_{\dot{p}} = 0 \Rightarrow PF_Y Y_p - Y - pY_p = 0 \Rightarrow PF_Y - p = \frac{Y}{Y_p} \Rightarrow \varepsilon = \frac{p}{PF_Y - p} \Rightarrow p* = \frac{\varepsilon PF_Y}{1+\varepsilon} \tag{6}$$

where $\varepsilon \equiv \frac{dY/y}{dp/p}$ is the price elasticity of the farm output, Y; for mathematical convenience, ε is hereafter considered to be a constant. The second Euler equation yields the optimal path for R&D in the processing sector:

$$W_R - \frac{d}{dt}W_{\dot{R}} = 0 \Rightarrow PF_Y Y_R e^{-rt} = e^{-rt}\left[c + pY_R\right] - \frac{d}{dt}\left(e^{-rt}\chi_{\dot{R}}\right) \tag{7}$$

The optimality condition in Equation (7) states that the firm adjusts its R&D up to the point where the firm's marginal revenue equals its marginal cost minus the time variation of the marginal impact of the net adjustment cost of R&D faced by the firm. Assuming quadratic net adjustment costs, $\chi(\dot{R}) = \frac{b(\dot{R})^2}{2}$, where the constant b is positive if the cost of adjusting R&D growth is higher than its benefit ($b < 0$, otherwise), Equation (7) can be rewritten as a second-order linear differential equation with constant coefficient and a constant term,

$$\ddot{R} - r\dot{R} + \frac{[PF_Y - p]Y_R}{b} = \frac{c}{b} \tag{8}$$

Its general solution is found in [31]:

$$R(t) = A_1 e^{mt} + A_1 e^{nt} + \overline{R} \tag{9}$$

where the characteristic roots m and n take the values

$$m,n = \frac{1}{2}\left\{r \,\substack{+\\-}\, \left(r^2 - 4\frac{[PF_Y - p]Y_R}{b}\right)^{1/2}\right\} \tag{10}$$

and the particular integral is

$$\overline{R} = \frac{c}{[PF_Y - p]Y_R} \tag{11}$$

The general solution is given by

$$R(t) = A_1\exp\left[\frac{1}{2}\left\{r + \left(r^2 - 4\frac{[PF_Y-p]Y_R}{b}\right)^{1/2}\right\}t\right] + A_2\exp\left[\frac{1}{2}\left\{r - \left(r^2 - 4\frac{[PF_Y-p]Y_R}{b}\right)^{1/2}\right\}t\right] + \frac{c}{[PF_Y-p]Y_R} \tag{12}$$

There are two possible scenarios for the general solution in Equation (12): $b < 0$ or $b > 0$. Considering the former, wherein the benefit of adjusting R&D is greater than its cost, the second root n may be negative. However, as both roots are real, the positive root m dominates. As t increases, the first term on the RHS grows increasingly larger and the second term dwindles away. Therefore, the path of R&D is explosive.

In order to avoid explosive paths for Equation (12), a second boundary condition for the problem in Equation (5) is necessary:

$$\lim_{t\to\infty} R(t) = \overline{R} \tag{13}$$

Considering the terminal condition in Equation (13) and the initial condition for R in Equation (5), we can calculate the constants of integration, A_1, A_2. Plugging these into Equation (9) yields the following general solution:

$$R(t) = \left(R_0 - \frac{c}{[PF_Y - p]Y_R}\right) \exp\left[\frac{1}{2}\left\{r - \left(r^2 - 4\frac{[PF_Y - p]Y_R}{b}\right)^{1/2}\right\} t\right] + \frac{c}{[PF_Y - p]Y_R} \tag{14}$$

A more interesting case arises when $b > 0$ and $r^2 < 4\frac{[PF_Y-p]Y_R}{b}$ because it yields a pair of complex roots. The second inequality is more likely to occur when the processing sector has a low discount rate, r, a large positive adjustment cost coefficient, b, and a large price differential between processed and raw products. When the values of the coefficients are such that $r^2 < 4\frac{[PF_Y-p]Y_R}{b}$, the characteristic roots will be the pair of conjugate complex numbers, $m, n = h \pm vi$, where $h = \frac{1}{2}r$ and $v = \frac{1}{2}\sqrt{4\frac{[PF_Y-p]Y_R}{b} - r^2}$. With complex roots, Equation (9) can be rewritten as

$$R(t) = e^{0.5rt}(A_3 \cos vt + A_4 \sin vt) + \frac{c}{[PF_Y - p]Y_R} \tag{15}$$

where $A_3 = A_1 + A_2 = A_2 = R_0 - \overline{R}$ and $A_4 = (A_1 - A_2)i = -(R_0 - \overline{R})i$. As h is positive, the R&D cycles are characterized by explosive fluctuations and the equilibrium is unstable.

The above analysis suggests that the critical parameter is b, the parameter of the net cost of adjustment of R&D growth in the processing sector. When $b < 0$ (i.e., when the benefits of adjusting R&D growth are higher than the costs of the adjustments), the model yields a stable equilibrium in which the convergence path is non-cyclical. However, if the parameter of the adjustment costs of R&D growth is positive (i.e., $b > 0$), the steady state equilibrium is unstable and the path of R&D is characterized by explosive fluctuations. Profit maximizing firms in the noncompetitive processing sector will always choose a level of R&D growth in which $b > 0$, given that this is the necessary and sufficient second-order condition to maximize W. This can be seen by calculating the Legrende condition, $W_{\dot{R}\dot{R}} = -be^{rt} < 0$ only if $b > 0$ [32].

4. Avoiding Explosive Cycles: The Optimal Control Model

The result from the previous section states that choosing a level of R&D growth that yields net adjustment costs that maximize profits over time (i.e., $b > 0$), and thereby putting processing sector firms on a cyclical and explosive path of R&D, is paradoxical, given the incompatibility between profits and infinite R&D at any given time. There are two ways to avoid this problem. The first is for the processing firm to set its time preference to zero (i.e., $r = 0$), which yields a never-ending R&D cycle with constant amplitude R&D fluctuation around its steady state equilibrium value $\overline{R}$. The second strategy of avoiding explosive R&D cycles is more realistic. It entails the *a priori* determination by the processing firm of the path of R&D growth and the R&D target level, as given by its R&D budget and research capacity. This is in line with the seminal insight that, in an environment of rapid change, a firm survives by pursuing a strategy that defines its own technological effort, R&D growth, and R&D target [33]. Assume a simple R&D growth,

$$\dot{R} = \beta(R - \overline{R}) \tag{16}$$

where $\overline{R}$ is the R&D target level. Such a strategy transforms the problem of Equation (5) into an optimal control problem, with the term, $\chi(\dot{R})$, vanishing to zero and with Equation (16) representing the dynamic constraint of the problem. In the optimal control problem, p is the processing sector control variable, and R is the state variable.

Denoted below by an asterisk are the steady state equilibrium for p, R, and the costate variable, λ (i.e., the shadow price of R&D), respectively,

$$PF_Y - p = \frac{Y}{Y_p} \Rightarrow p* = \frac{\varepsilon PF_Y}{1+\varepsilon} \tag{17}$$

$$R* = \overline{R} \tag{18}$$

and

$$\lambda* = (r-\beta)^{-1}(Y\frac{Y_R}{Y_p} - c) \tag{19}$$

It is important to stress that Equations (17) and (18) are the same as the solutions of the variational calculus problem of Equation (5), which indicates the consistency of the formulation of the problem of the representative food processing sector firm. The discussion regarding the convergent path towards the steady state is related to Equation (19), and in particular to the positive link between λ and β, which states that an increase in β, the coefficient of the velocity of adjustment of R&D, leads to an increase of the opportunity cost of R&D, such that the firm uses less of it. Another special relation that deserves attention is the fact that β is limited by r, given that it cannot be greater than r provided that c is negligible as compared to the term $Y\frac{Y_R}{Y_p}$.

The steady state value of the processing sector R&D, R*, given by Equation (18) is not impacted by any exogenous variables in the model. The relevant comparative statics analysis concerns the impact of P, ε, and S on the farm output price, p, through the analysis of Equation (17). An increase in the price elasticity of farm output, ε, increases p. If the price of final goods, P, increases, a higher p is yielded. Innovations at the farm level, S, also lead to a higher p. Additionally, we can assess the impact of R* on p*, which is positive (i.e., an increase in the processing sector R&D yields higher agricultural prices). Given the positive effect of higher agricultural prices on farm output (see Equation (3′)), an increase in either R*, P, ε, or S will have a positive impact on the steady-state value of farm output, while the positive relationship between labor and output supports the argument that employment grows in the farm sector [34]. Lastly, the impact of S (i.e., innovations in the farm sector) can be boosted by public policy that is generally associated with agricultural research at universities and public agencies. Thus, in our model, any policy that stimulates the production of these public goods and services has a positive impact on agricultural prices and output.

4.1. Farmers with Entrepreneurial Talent

Assume that farmers differ in entrepreneurial talent e, $e \geq 0$, where e = 0 means that the farmer has no entrepreneurial talent. Entrepreneurial talent is considered an exogenous variable, and an additional argument in the farmer's production function, $f(e, Y, R, S)$, $f_e > 0$. Solving the model with this new production function, the impact of entrepreneurial talent on the steady state agricultural price is positive, and it also increases, as expected, steady-state farm output. An alternative way to rationalize farmer-entrepreneurial talent is to assume that a higher e leads to more agricultural innovation at the farm level (i.e., a higher S). In this capacity, entrepreneurial talent amplifies the positive impact of S on farm price and output.

4.2. The R&D Patent Race

If there are firms doing R&D on similar projects in the noncompetitive processing sector, they compete to obtain a patent, and the first firm to complete its R&D gets the patent. Suppose the representative firm believes that the cumulative distribution function of the rival invention by time t is exponential [35]:

$$G(t) = 1 - e^{-zt}, \tag{20}$$

where $z > 0$ is constant. The representative firm does R&D at t only if no rival has obtained a patent, so its problem becomes

$$W = \int_0^\infty [PF(Y(R,S,p)) - cR - \chi(\dot{R}) \ - pY(R,S,p)][1 - G(t)]e^{-rt}dt \tag{21}$$

Substituting Equation (20) into Equation (21) yields

$$W = \int_0^\infty [PF(Y(R,S,p)) - cR - \chi(\dot{R}) \ - pY(R,S,p)]e^{-(r+z)t}dt \tag{22}$$

Essentially, the patent race increases the rate of discount for the representative firm from r to $r + z$. Thus, considering the case wherein the firm ignores its own time preference (i.e., $r = 0$), explosive cycles will not be eliminated. In this case, we solve the optimal control model by setting $\chi(\dot{R})$ to zero and considering Equation (16) as a dynamic constraint, whereby the presence of a patent race does not change steady state equilibrium p and R, it only reduces the shadow price, λ, of R&D.

5. Technological Innovation and Agriculture in the U.S.: A Brief Look at the Data

Data from the U.S. Department of Agriculture, World Intellectual Property Organization, and the Federal Reserve Bank of St. Louis that are presented in Table 3 generally support multiple facets of the formal model developed in the previous section of the study. First, the prices of dairy, feed crops, fruits and nuts, food grains, meat animals, oil crops, poultry and eggs, vegetables and melons, and other crops all increased between the two time periods—1994–2003 and 2004–2013—under examination in Table 3. These increases in agricultural prices are, as pointed out in Table 3, associated with increases in both food processing sector innovations and public and private support (funding) for agricultural R&D. As indicated in the table, the number of food chemistry and biotechnology patents granted in the U.S. climbed from a per-year average of 1587 and 3375, respectively, during the 1994–2003 period to annual averages of 1895 and 3616, respectively, over the more recent 2004–2013 period. Similarly, public and private agricultural R&D funding grew from annual averages of \$4.698 billion and \$5.267 billion, respectively, during 1994–2003 to annual averages of \$5.033 billion and \$5.916 billion, respectively, during 2004–2013. Although not shown in the table, these innovation gains are also consistent with agricultural production totals. Such is the case in each agricultural category listed with the exception of food grains and vegetables and melons, whose production totals are essentially stable over the two time periods, 1994–2003 and 2004–2013.

Table 3. R&D and the U.S. Agricultural Economy, 1994–2013.

Price Indices and R&D	**Time Period**	
	2004–2013	**1994–2003**
Agricultural Price Indices		
Dairy	1.126	0.907
Feed Crops	1.637	0.995
Fruits & Nuts	1.177	0.804
Food Grains	1.654	1.076
Meat Animals	1.056	0.717
Oil Crops	1.666	1.054
Poultry & Eggs	1.149	0.873
Vegetables & Melons	1.173	0.900
Other Crops	1.119	0.950

Table 3. *Cont.*

Price Indices and R&D	Time Period	
	2004–2013	1994–2003
Food Processing Sector R&D		
Food Chemistry Patents Granted	1895	1587
Biotechnology Patents Granted	3616	3375
Public Agricultural R&D Funding	$5.033 billion	$4.698 billion
Private Agricultural R&D Funding	$5.916 billion	$5.267 billion
Final Goods Price Indices		
Beef & Veal Products	146.0	103.5
Canned Dry Beans	144.3	119.8
Canned Fruits & Juices	177.1	137.0
Mayonnaise, Salad Dressings & Sandwich Spreads	192.7	145.0
Processed Fruits & Vegetables	167.0	127.6
Wheat Flour	187.5	115.6

The numbers above are annual means. The public (private) agricultural R&D series runs through 2009 (2007), and the beef and veal products series are based on partial data. Regulars: United States Department of Agriculture (USDA), World Intellectual Property Organization (WIPO), and Federal Reserve Bank of St. Louis (FRBSL).

Lastly, the increases in agricultural prices pointed out in Table 3 are also associated with increases in a number of final (processed) goods prices, such as those for beef and veal products, canned dry beans, canned fruits and juices, mayonnaise, salad dressings and sandwich spreads, processed fruits and vegetables, and wheat four. These associations are also consistent with the findings from the theoretical model presented in the previous section of the study.

6. Concluding Remarks

This study fills a gap in the theoretical literature concerning the rural economy by presenting and analyzing a dynamic model of technological innovation and agricultural entrepreneurship. The dynamic model presents two economic sectors—a non-competitive industrial sector (i.e., food processing), which is the leader, and an agricultural sector, which is considered to be the follower. The formal model focuses on process technology and innovation at both the farm level and the food processing sector precisely because this is the dimension that is most relevant in terms of interaction (integration) between these two entities.

The solutions from the dynamic model display explosive cycles for R&D, wherein increases in processing sector R&D expenditures grow ever larger. These cycles are avoided when processing firms generate an optimal control model with stable solutions by setting the dynamic path of R&D and its target. The theoretical implications of the model suggest that, in equilibrium, increases in processing sector R&D, public and private agricultural research, entrepreneurial talent, and the prices of final goods work to increase agricultural prices and output. U.S. data for the relatively recent period of 1994–2013, indicating positive relationships between agricultural prices on the one hand and processing sector R&D, public and private agricultural research, and final goods prices on the other, support the practical implications of our dynamic model.

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References

1. McElwee, G.; Atherton, A. Rural entrepreneurship. In *World Encyclopedia of Entrepreneurship*; Dana, L.P., Ed.; Edward Elgar Publishing: Cheltenham, UK, 2011; pp. 377–384.
2. Pender, J.; Marré, A.; Reeder, R. Rural wealth creation: Concepts, measures and strategies. *Am. J. Agric. Econ.* **2011**, *94*, 535–541. [CrossRef]
3. Finsterbush, K.; Kuennen, D. A look at business recruitment as a rural development strategy. *Policy Stud. J.* **1992**, *20*, 218–229. [CrossRef]
4. Heimlich, R.E.; Anderson, W.D. *Development at the Urban Fringe and Beyond: Impacts on Agriculture and Rural Land*; ERS Agricultural Report No. 803; United States Department of Agriculture: Washington, DC, USA, 2001.
5. Reeder, R. *Retiree-Attraction Policies for Rural Development*; ERS Agricultural Report No. 741; United States Department of Agriculture: Washington, DC, USA, 1998.
6. Wortman, M.S., Jr. Rural entrepreneurship research: An integration into the entrepreneurship field. *Agribusiness* **1990**, *6*, 329–344. [CrossRef]
7. Fuller-Love, N.; Midmore, P.; Thomas, D.; Henley, A. Entrepreneurship and rural economic development: A scenario analysis approach. *Int. J. Entrep. Behav. Res.* **2006**, *12*, 289–305. [CrossRef]
8. Vaillant, Y.; Lafuente, E. Do different institutional frameworks condition the influence of local fear of failure and entrepreneurial examples over entrepreneurial activity? *Entrep. Reg. Dev.* **2007**, *19*, 313–337. [CrossRef]
9. Carter, M.R.; Barrett, C.B. The economics of poverty traps and persistent poverty: An asset-based approach. *J. Dev. Stud.* **2006**, *42*, 178–199. [CrossRef]
10. Just, R.; Chern, W. Tomatoes, technology, and oligopsony. *Bell J. Econ.* **1980**, *11*, 584–602. [CrossRef]
11. Wann, J.J.; Sexton, R.J. Imperfect competition in multiproduct food industries with application to pear processing. *Am. J. Agric. Econ.* **1992**, *74*, 980–990. [CrossRef]
12. Hamilton, S.; Sunding, D. The effect of farm supply shifts on concentration and market power in the food processing sector. *Am. J. Agric. Econ.* **1997**, *79*, 524–531. [CrossRef]
13. Hamilton, S.F.; Sunding, D.L. Returns to public investments in agriculture with imperfect downstream competition. *Am. J. Agric. Econ.* **1998**, *80*, 830–838. [CrossRef]
14. Alston, J.; Sexton, R.; Zhang, M. The effects of imperfect competition on the size and distribution of research benefits. *Am. J. Agric. Econ.* **1997**, *79*, 1252–1265. [CrossRef]
15. Chavas, J.; Cox, T. A nonparametric analysis of the influence of research on agricultural productivity. *Am. J. Agric. Econ.* **1992**, *74*, 583–591. [CrossRef]
16. Dryburgh, C.; Doyle, C. Distribution of research gains under different market structures: The impact of technical change within the UK dairy industry. *J. Agric. Econ.* **1995**, *46*, 80–96. [CrossRef]
17. Pato, M.L.; Teixeira, A.A.C. Twenty years of rural entrepreneurship: A bibliometric survey. *Sociol. Rural.* **2016**, *56*, 3–28. [CrossRef]
18. Gray, A.; Bohlje, M.; Amanor-Boadu, V.; Fulton, J. Agricultural innovation and new ventures: Assessing the commercial potential. *Am. J. Agric. Econ.* **2004**, *86*, 1322–1329. [CrossRef]
19. Fuglie, K.O.; Toole, A.A. The evolving institutional structure of public and private agricultural research. *Am. J. Agric. Econ.* **2014**, *96*, 862–883. [CrossRef]
20. Kahan, D. *Entrepreneurship in Farming*; Food and Agricultural Organization of the United Nations: Rome, Italy, 2013.
21. Bagi, F. *Agritourism Farms are More Diverse than Other U.S. Farms*; Amber Waves. United States Department of Agriculture: Washington, DC, USA, 2014.
22. Schilling, B.J.; Attavanich, W.; Jin, Y. Does agritourism enhance farm profitability? *J. Agric. Resour. Econ.* **2014**, *39*, 69–87.
23. Schilling, B.J.; Sullivan, K.P. Characteristics of New Jersey agritourism farms. *J. Food Distrib. Res.* **2014**, *45*, 161–173.
24. Van der Sluis, J.; van Praag, M.; Vijverberg, W. Education and entrepreneurship selection and performance: A review of the empirical literature. *J. Econ. Surv.* **2008**, *22*, 792–841. [CrossRef]
25. Unger, J.M.; Rauch, A.; Frese, M.; Rosenbusch, N. Human capital and entrepreneurial success: A meta-analytical review. *J. Bus. Ventur.* **2011**, *26*, 341–358. [CrossRef]

26. Mayer-Haug, K.; Read, S.; Brinckmann, J.; Dew, N.; Grichnik, D. Entrepreneurial talent and venture performance: A meta-analytic investigation of SMEs. *Res. Policy* **2013**, *42*, 1251–1273. [CrossRef]
27. Putnam, R. The prosperous community: Social capital and public life. *Am. Prospect* **1993**, *4*, 35–42.
28. Atterton, J. The 'strength of weak ties': Social networking by business owners in the Highlands and islands of Scotland. *Sociol. Rural.* **2007**, *47*, 228–245. [CrossRef]
29. Meccheri, N.; Pelloni, G. Rural entrepreneurs and institutional assistance: An empirical study from mountainous Italy. *Entrep. Reg. Dev.* **2006**, *18*, 371–392. [CrossRef]
30. North, D.; Smallbone, D. Innovative activity in SMEs and rural economic development: Some evidence from England. *Eur. Plan. Stud.* **2000**, *8*, 87–106. [CrossRef]
31. Chiang, A.; Wainwright, K. *Fundamental Methods of Mathematical Economics*, 5th ed.; McGraw-Hill: New York, NY, USA, 2005.
32. Bronshtein, I.N.; Semendyayev, K.A. *Handbook of Mathematics*, 3rd ed.; Springer: New York, NY, USA, 1997.
33. Drucker, P.F. *The Age of Discontinuity*; Harper & Row: New York, NY, USA, 1969.
34. Labrianidis, L. Fostering entrepreneurship as a means to overcome barriers to development of rural peripheral areas in Europe. *Eur. Plan. Stud.* **2006**, *14*, 3–8. [CrossRef]
35. Kamien, M.I.; Schwartz, N.L. *Dynamic Optimization*, 2nd ed.; North-Holland: Amsterdam, The Netherlands, 1991.