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**Potato Paradoxes**

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**Working Paper No. 135**

**POTATO PARADOXES**

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## Abstract

Potato cultivation in Ireland during the Great Famine is analyzed in economic terms. Economic dynamics are complicated in crops which serve both as consumption and capital goods. "Seed" potatoes must be carried over for planting the following season. These inventories are a form of savings and account for a sizable portion of total output. The intertemporal tradeoffs associated with seed crop inventory decisions can produce unusual dynamic responses that could be confused with pathological behavior, such as Giffen goods. For instance, an increase in demand can reduce consumption; a decrease in supply can increase consumption. In fact, price and output data in Ireland of the 1840's are inconsistent with the Giffen paradox. Instead, the tragic events there are well described by a model in which a permanent decline in potato productivity (the blight) was at first mistaken as a transitory crop failure. These mistaken judgements provoked "over saving" of seed crop among a population in dire circumstances, when, with the benefit of hindsight, consumption of seed crop capital was warranted. Since the blight was unknown prior to the 1840's, the Irish experience can be expressed as an unfortunate form of Knightian uncertainty combined with conventional intertemporal dynamics. Expectational errors about potato productivity delayed necessary agricultural adjustments and contributed to the catastrophe in later years.

# POTATO PARADOXES

Sherwin Rosen<sup>1</sup>

## I. Introduction

Potatoes are very interesting goods. They have been an important food staple in the world since the 18th century, serving as the main (nonprotein) source of food energy for many people at various times and places (Salaman, 1949; Heiser, 1990). Yet they also have been implicated in disastrous famines. And because of their importance in the diets of many poor people, potatoes are a leading practical example of an inferior good, possibly even of the dreaded Giffen good. But what makes them especially interesting for economics is the little known fact that potatoes are *capital goods* as well as consumption goods. Intertemporal elements of choice affect supply decisions. Some economic consequences of this fact are pursued in what follows.

Potatoes are not produced commercially from seed. They are reproduced vegetatively. A significant portion of the crop is withheld from final consumption, and their buds (or “eyes”) are replanted for next year’s crop. Seed crop capital is an important component of total production even in modern conditions, depending on climate, soil quality, and agricultural technology. In Russia today seed potatoes may account for as much as 25% of the crop. In the U.S. it is 7 - 9%. It probably was on the order of 15% in 19th Century Ireland during the famine era (Bourke, 1993).

Seed stock inventory adjustments affect supply decisions in unusual ways that can confuse demand and supply responses in many situations. Dynamical responses to shocks can lead to bizarre results. For example, when demand increases short-term consumption can fall (Rosen, 1987). When supply decreases, consumption can increase even if demand is downward sloping, an effect that might be wrongly attributed to

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<sup>1</sup>I am especially indebted to Cormac O Grada for advice and information on the Famine and for criticism of an initial draft. O Grada (1993, 2nd ed), Mokyr (1983), and Bourke (1993) are the essential economic sources on the Irish Famine. I have used all of them extensively, though not always with detailed attribution. Thanks also go to D. Gale Johnson and Stanley Engerman for discussion and comments. I take full responsibility for error and interpretations.

the Giffen paradox.

During the 150th anniversary of the Great Irish Famine of 1845-47 it is appropriate to draw out these implications and test them on available data. Another reason for economists to study that unfortunate episode is that the appearance of the fungus *p. infestans* on the Irish potato crop of 1845 is a pathology that virtually duplicates the conceptual experiment needed to analyze dynamic market responses to an unusual kind of production shock. The pest was unknown prior to that time, and its arrival proved permanent. Its effect dominated all other factors affecting demand and supply of potatoes. The next section sketches an abstract economic model of the potato market. Later sections interpret some of the Irish data in its light.

Given the unusual diets of rural dwellers in Ireland in the 1840's, the major outlines of the disaster are well described by a rational model in which a permanent adverse decline in potato productivity was at first mistaken for a transitory one. The blight was completely out of the realm of European agricultural experience in 1845. It was not in the information set. In the first year of the famine, anticipation that productivity would return to normal induced growers to carry over excess seed inventory for planting the next year. In the first year it is clear, in hindsight, that seed stocks should have been eaten instead. Gross over saving of people in such dire circumstances had catastrophic consequences later on, and delayed substitution to other crops that could have eased, though hardly eliminated the suffering later.

## II. The Model

This section outlines a decentralized market model for goods, like potatoes, that serve as both consumption and capital. Intertemporal responses to transitory and permanent shocks are described and used in subsequent sections to interpret the Irish experience beginning in 1845.

### A. Technological Structure

Let  $S_t$  be the size of the seed crop,  $g$  the net reproduction rate,  $Q_t$  total output and  $C_t$  consumption of the good. The production function is

$$(1) \quad Q_{t+1} = (1+g)S_t$$

with  $g > 0$ . In 19th Century Ireland, the 15% seed-output ratio meant that one seed potato produced about  $1/.15 = 7.5$  potatoes next season and  $g = 6.5$ . In the U.S. today it is 12-to-15 to 1 and  $g \in [11 - 14]$ . Total output is used for seed crop and consumption,

$$(2) \quad Q_t = S_t + C_t$$

## B. Behavioral Relationships

To simplify, assume no intertemporal elements in consumption demand between seasons. Then steady-state market demand is  $C_t = C(p_t)$ , where  $p$  is the price of the good. Supply is determined by farmers' decisions to either sell their crops for immediate consumption or hold some of them over the season for seed, replanting, and selling or planting crop next year. Ignoring inputs other than seed stock<sup>2</sup>, the return from selling is the current price  $p_t$ . Withholding a unit of stock and replanted it produces  $1+g$  units next season. These can be sold for expected price  $p_{t+1}$ . Let  $k(S)$  be the direct (noninterest) marginal costs of planting and storage, with  $k'(S) \geq 0$ , and let  $r$  be the rate of interest. Defining  $G = (1+g)/(1+r)$ , the marginal return from replanting is  $Gp_{t+1} - k(S)$ . If the crop is simultaneously consumed and replanted for future production, profit must be equal at both margins, or

$$(3) \quad p_t = Gp_{t+1} - k(S_t).$$

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<sup>2</sup>Consider (1) as a reduced form in which other inputs have been optimized out at the first stage and their factor prices impounded in  $g$ . In reality, productivity  $g$  varies with soil fertility on each farm. At the market level, limited amounts of higher quality land make  $g$  a decreasing function of aggregate output, so (1) must be interpreted as a local approximation. Rising supply price is modeled as arising from increasing marginal holding costs rather than from diminishing returns directly, but these are (approximately) equivalent for dynamics (see below).

The crop is renewed if  $G > 1$ . Otherwise, it is not economic to renew and cultivation ceases.

The arbitrage condition in (3) is one restriction on the observed paths of stocks and supply prices.

Combining the demand curve, production function, and storage-consumption-production identity, stock-flow dynamics imply another restriction

$$(4) \quad S_{t+1} - S_t = gS_t - C(p_{t+1})$$

### C. Market Equilibrium

If demand and supply are unchanging, long-run equilibrium values of  $p$ ,  $C$ ,  $Q$  and  $S$  are defined by

(2) - (4), with  $p_t = p_{t-1} = \dots = p$  and  $S_t = S_{t-1} = \dots = S$ . Equation (3) becomes

$$(5) \quad p = k(S)/(G - 1)$$

The long-run supply price of the good is the marginal planting and carrying cost of inventory grossed up by the inverse of the net internal rate of return from growing the crop. This rate of return,  $G - 1 = (g - r)/(1+r)$ , must be positive for inventories to be sustained. When marginal cost is increasing in  $S$ , equation (5) defines a rising curve in the  $(p,S)$  plane.

At these steady-state values, equation (4) describes the seed inventory required to sustain long-run consumption

$$(6) \quad S = C(p)/g$$

(6) defines a decreasing curve in the  $(p,S)$  plane if the good is normal and an increasing curve if it is Giffen.

See figures 1 and 2.

Using (5), equation (3) can be arranged to read as

$$(7) \quad p_{t+1} - p_t = (1-G)(p_{t+1} - p) - [k(S_t) - k(S)].$$

Since  $1 - G < 0$ , the price change  $p_{t+1} - p_t$  is negative for all values of  $(p, S)$  above the curve defined by (5) and positive for all values of  $(p, S)$  below it. The phase arrows in figures 1 and 2 point down above the stable manifold (5) and point up below it.

Similarly, using (6), equation (4) becomes

$$(8) \quad S_{t+1} - S_t = g(S_t - S) - [C(p_{t+1}) - C(p)]$$

$S_{t+1} - S_t$  is positive and stock is growing for any pairs  $(p, S)$  that lie above the curve defined by (6). Stock falls for  $(p, S)$  pairs that lie below it, so the phase arrows point to the right above that stable manifold and to the left below it.

The motions defined by (3) and (4) for any initial conditions are described by familiar saddle-point dynamics in the  $(p, S)$  plane.<sup>3</sup> Applying the condition that the discounted value of expected future crop is bounded, observed trajectories trace the arrows that converge on the intersection of the  $p$  and  $S$  curves in figures 1 and 2.

Figure 1 depicts downward sloping demand. For instance, if a *transitory* shock reduced initial stock below its steady state level, price jumps initially and thereafter declines to its long-run value as seed inventories grow back to normal levels. After the shock hits, larger inventories are needed to sustain long-

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<sup>3</sup> Linearizing  $k(S)$  and  $C(p)$  in the neighborhood of the steady state yields a pair of linear difference equations. The associated characteristic equation has two real roots, whose product is  $(1+r)$ . In the general solution the unstable root larger than  $(1+r)$  is eliminated by the boundary condition. Its effect is only seen in the forward looking part of the particular solution. Notice that in this system, it makes no difference whether the  $p$  manifold is increasing due to rising inventory costs or due to directly diminishing returns, as asserted above.

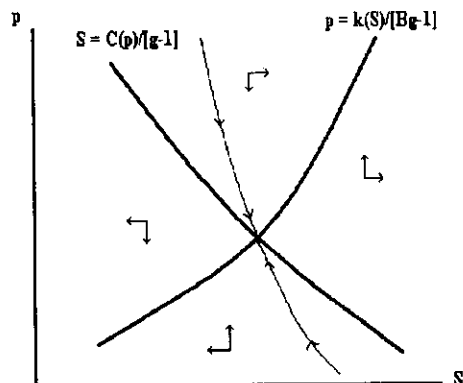


Figure 1

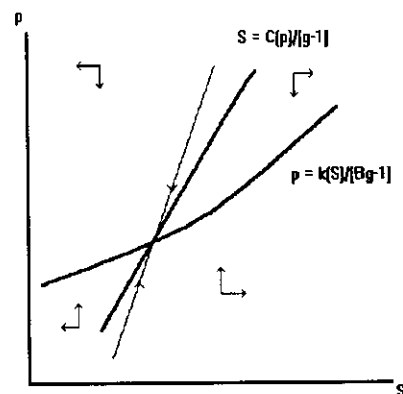


Figure 2

term consumption. A high initial price discourages current consumption and encourages the accumulation of seed stock inventory. Prices thereafter naturally fall as production and inventory return to their steady-states. Conversely, if a *transitory* shock increases initial stocks above  $S$ , the unexpected bounty causes price to fall below  $p$  to encourage extra consumption and gradually drive stocks back down to their normal levels. The speed of the subsequent adjustments varies in proportion to  $g$  and  $r$ .

Figure 2 depicts a Giffen good. Quantity demanded is increasing in price. Here the  $p$  curve in equation (5) is upward sloping because high prices provoke greater consumption. Notice that the stable arrows slant in the opposite direction to the normal demand case in figure 1. If initial inventories are excessive, price must be driven up to encourage the extra consumption needed to work them down to steady state levels. If initial stocks are too small, price must be driven down to discourage consumption and encourage accumulation. From such stuff are Paradoxes made<sup>4</sup>.

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<sup>4</sup> If the Giffen effect is strong enough the  $p$  curve is flatter than the  $S$  curve in figure 2. In this case the associated linear system has explosive cycles: its characteristic roots are complex numbers with modulus greater than  $1+r$ . The market is Hicksian unstable. If the  $S$  curve is rising and cuts the  $p$  curve more than once, only those points where it cuts from below are stable.

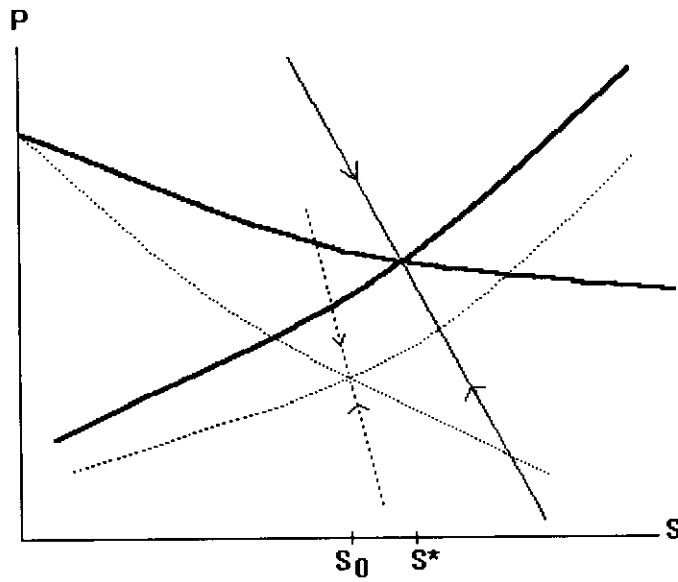
### D. Changes in Supply and Demand

Permanent shocks to demand or supply shift the steady-state loci in figures 1 or 2 and the initial conditions. The dynamic consequences are tracked by following the stable arrows of the altered system to the new equilibrium. For example, an unanticipated, but thereafter *permanent* increase in demand shifts the S-C curve in (6) to the left. If seed stock is too small at the time the shock occurs, price initially rises to discourage consumption and encourage investment in seed inventory. The high price gradually falls thereafter to its higher steady state value and consumption increases. That the quantity supplied to the consumption market can initially *decrease* in response to a permanent increase in demand is not so paradoxical once the capital aspects of the good are recognized (Rosen, 1987)

Another interesting experiment more relevant for the famine is an unanticipated but thereafter *permanent* shock to supply. Suppose the productivity factor  $g$  falls unexpectedly and remains smaller forever. Depending on initial conditions, such a shock can cause price to *fall* initially, even if demand is normal. Such an event could easily be confused with a Giffen effect, but is just another odd economic implication of the dual consumption/capital aspects of the crop.

A decline in  $g$  reduces the return to cultivation in (5) and raises the minimum long-run supply price  $k(S)/(G-1)$ . The  $p$  locus shifts up, as in figure 3. But lower productivity of seed requires *larger* inventories to sustain any given level of consumption in the long-run:  $C(p)/g$  increases and the  $S$  locus shifts to the right. Both forces guarantee greater market price in the long-run, but the effect on seed inventory is ambiguous and can go in either direction. Figure 3 is drawn for downward sloping demand. If, at the time the shock hits, “initial” stock is less than the new steady state stock, the productivity decline causes price to rise to limit consumption and encourage accumulation. But if instead these initial stocks exceed the long run target, price falls to induce capital consumption. Whether target inventories rise or fall depends on the elasticity of demand for the good.

To see this later point, define  $\eta = d\log C/d\log p$  as the price elasticity of demand and  $\epsilon$  as the price



**Figure 3**

elasticity of long-run supply. Comparative statics on (5) and (6) yield

$$(9) \quad \partial \log P / \partial g = -[(1 - r/g) + \epsilon] / [\epsilon(g - r)(1 - \eta/\epsilon)] < 0$$

$$(10) \quad \partial \log S / \partial g = -[\eta + (1 - r/g)] / [(g - r)(1 - \eta/\epsilon)]$$

Market stability requires  $(1 - \eta/\epsilon) > 0$  whether or not the good is Giffen.

Equation (9) shows that long-run price is decreasing in  $g$ . But the sign of (10) is ambiguous. The derivative  $\partial \log S / \partial g$  is positive or negative according to whether the elasticity of demand exceeds or falls short of  $1 - r/g$ . Demand must be sufficiently elastic for  $S$  to fall when  $g$  falls: Then steady-state consumption

decreases so much that steady-state inventories decrease in spite of the fact that more seed crop is required to sustain any level of output. But if demand is sufficiently inelastic steady-state seed inventories *increase* when  $g$  falls. Since consumption doesn't fall so much, the smaller productivity of seed requires larger seed-stock to sustain it. In this case carry-over stock adjustments exacerbate price and consumption movements. Notice that if demand is sufficiently elastic, the adverse shock conceivably could cause price to fall and consumption to increase initially. Dumping inventory on the consumption market smooths the necessary price and consumption adjustments to the new steady state rather than worsening them.

### III. The Famine

Though year-to-year fluctuations in potato output were not uncommon in Ireland, the blight made its first appearance there in 1845 (Mokyr, 1983). Previous transitory shortfalls in potato output in 1817 and 1825 had been associated with high prices, hunger, and hard living conditions. But true famine, defined by significant excess (age-adjusted) mortality experience, did not occur prior to 1845 (O Grada, 1993). Furthermore, up to that time the Irish were not so dependent on potatoes. The crop did not account for such a large share of total food intake.

Innovations in higher yielding varieties, the relatively benign past history of crop failure, the remarkable and growing dependence on potatoes as the major food for one-third or more of the Irish population, and the sheer magnitude of the catastrophe itself leaves no doubt that the blight was an entirely unexpected event. It was one of the most unfortunate "natural experiments" in modern history. On the eve of the famine per capita consumption of potatoes is estimated to have been as large as 9 lbs. (40 - 50 potatoes) per person per day (Bourke, 1993). Diets were astonishingly concentrated on potatoes, especially in rural areas. Grain was grown in rural Ireland, but was either sent to towns or exported abroad.

Given the demonstrated capacity of Irish agriculture to deal with transitory fluctuations in yields in earlier years, surely the malingering, permanent effect of the blight on the productivity of potato cultivation in

Ireland was the true cause of the Great Famine.<sup>5</sup> Unlike the internal political factors that have been responsible for most famines (Sen, 1981), there just wasn't enough food to go around in Ireland. The blight decreased potato productivity for the next 35 years. Productivity improved only when effective pesticides developed in France for phylloxera and viticulture spread to other uses throughout the world.

During the famine years potato output fell by half in the first year. In the second year, there were no significant declines in plantings relative to previous years, yet output fell by 80 percent (Bourke, 1993). Cultivation dropped by major proportions thereafter. The long-run price of potatoes relative to wheat and oats almost doubled between pre- and post famine eras (Solar, 1989), implying that the blight reduced permanent productivity by 50 percent.<sup>6</sup>

Potato prices during the period collected by Solar (1989) and O Grada (1993) appear in the appended graphs. Average annual prices per pound in urban markets increased more than three-fold during the famine years compared to the prefamine period. The increase was sharply concentrated in 1845-47. Prices declined to their new steady state post-famine, post-productivity-shock levels fairly soon thereafter.

Applying the model to these data requires auxiliary hypothesis about grower expectations. The actual shock is well described by a single downward step-function in  $g$  that occurred without warning in 1845 and continued for the next three decades. However, growers' perceptions of what was going on were much different than that. Their grossly inaccurate anticipations had dramatic intertemporal consequences.

The dynamics are well described by a two-stage version of the model. In the first stage growers were

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<sup>5</sup> To put the disaster in proper perspective, the famine killed at least 12% of the population over a three year period. Another 6- 8% migrated to other countries. In terms of the percentage of population affected, the 1845-8 famine is one the largest ever recorded. Other famines have killed more people in total because the affected populations were larger, not the percentage exposure. For instance, the 40 million (!) or more people who perished in the Chinese famine of 1958-62 were 5 or 6% of the population. In comparison to other disasters in living memory, WW II casualty rates (military and civilian) in all countries except Yugoslavia were much smaller than 12% (Wright, 1965).

<sup>6</sup> Pre- and post-famine gross yields per acre in Ireland do not differ much because acreage on less productive land fell drastically in the latter period. Since aggregate yields contain these changing composition effects, inferences about productivity changes directly attributable to the blight from are more secure from relative price data than from aggregate quantity data

grossly mistaken in judging the 1845 shock as transitory rather than as permanent. This interpretation is supported by the observation that 1846 plantings largely remained at their pre-famine levels. The second stage is the realization that potato productivity had in fact fallen permanently after the abysmal harvest of 1846. The transient dynamics of figure 1 and 2 apply in the first year or so, and the permanent dynamics in figure 3 apply thereafter.

If planters regarded 1845 as a temporary aberration and thought that productivity would return to normal the following year, the available data are entirely consistent with figure 1, but not with figure 2. Given the 50% shortfall in the 1845 season, seed crop inventories hardly could have been considered excessive. Yet the 1846 planting rivaled the size of the 1845 planting. Prices had to be driven sky high to discourage consumption and sustain a constant seed stock investment for 1846 out of a much smaller harvest. If, in normal years, 15% of the crop was held over for planting, in 1845 more like 30% of output was held back for planting following year. This is a remarkably high rate of saving for the future under drastic current conditions.

Though potatoes in Ireland were inferior goods, but they were definitely not Giffen goods. Recently, an interesting paper by Davies (1994) incorporated survival constraints into preferences to rationalize Giffen goods. The idea is that when an agent close to subsistence specializes food consumption on one item, a reduction in price frees-up income and liberates the consumer from binding nutritional constraints. It allows less basic and “higher level” wants to be satisfied. If prices increase, expenditure on other things must fall to satisfy the survival constraint. That survival was a serious consideration in Ireland of the 1840s is not in dispute. But the sad fact is that the survival constraint (especially in 1846 and 1847) was not binding. Since the first year price rose drastically and consumption fell, the transient dynamics in figure 1 proves that potatoes weren’t Giffen.<sup>7</sup>

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<sup>7</sup> Earlier, Dougan (1982) analyzed the dynamic implications of Giffen goods using the standard myopic, Hicksian stability framework. He found the Giffen hypothesis implausible. In that respect this analysis is a natural extension of his.

Had growers been aware in 1845 that the drop in potato productivity was permanent, they would have eaten more of their seed crop that year, prices would not have risen so much, and plantings in 1846 would have been much smaller. They would have switched production to other foods. The consequences of the blight would not have been so dire on both accounts.

An experiment like figure 3 takes over at the realization that the shock is permanent, after the second disastrous crop failure of 1846. The blight-induced productivity decline shifted the steady-state curves from the dotted lines to the solid lines in the figure. At the aggregate level, steady-state stocks and consumption decreased dramatically, mostly caused by the extraordinary demographic changes in the economy. But at the per capita level relevant for understanding farmers' behavior, it is possible that growers anticipated inelastic demand because these demographic changes were unforeseen. In that case even more seed stocks would have been held back and would have contributed to the misery of the outer years. But this last effect is not identified with the data at hand: whether growers considered demand to be elastic or inelastic, price would rise and consumption would fall.

Before examining other evidence on the elasticity of demand for potatoes, it is necessary to consider some qualifications and describe other social aspects of the Irish "potato culture."

#### IV. Qualifications for Trade

The model assumes that the potato economy in Ireland was essentially closed. Were potatoes freely traded among countries, and had the blight been greater in Ireland than elsewhere,<sup>8</sup> imports and intertemporal rearrangements of world consumption across countries could have made up the Irish shortfall. Since the blight was not nearly so extensive in other European countries, the enormous price variations observed in

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<sup>8</sup>The blight was endemic in South America, where the potato originated, but Europe was blight-free because *p. Infestans* could not survive the long sail voyage. The shorter steamship voyage changed all that. It is ironic that much later the blight destroyed the South American crop, and blight-resistant varieties were imported from Europe are grown there today. Nothing is left of the native South American varieties (Heiser, 1990).

Ireland require substantial limitations on the international potato trade. Since potatoes mostly consist of water, transportation costs per unit nutrient value are large compared to more commonly traded foods such as grain. The high transport costs of the mid-19th Century made potato trade relatively unimportant, but not zero. Irish potatoes had been exported, and even in 1845 some were sent to the low countries reporting blight. Nonetheless, imports of potatoes for Irish consumption were trivial.

Trade in seed crops are more interesting economically. Potatoes are so productive as capital that this requires a much smaller volume of trade and involves lower costs per unit value as capital than as consumption. In fact high yielding new varieties often were exported. The Irish Potato was known throughout the world. But the key issue is imports. My analysis plays off the need to abstain from current consumption and retain seed to produce next year's crop. Full consumption of seed crops in any period drives production to immediate extinction in a closed system. Significant importation of seed crop breaks the sharp constraint that links current consumption of seed inventory to smaller future production. Small amounts of seed potatoes were imported prior to the blight by some of the larger growers seeking higher yielding varieties with better taste. But during the famine years, there is no evidence of significant seed imports. The Irish potato economy was essentially closed.

The standard economic arguments for restricted trade and limited intertemporal substitution revolves around capital market imperfections or, in more fashionable terminology, "liquidity constraints." The people who suffered most from the famine were rural dwellers--small holders, tenants, and laborers operating largely in a subsistence economy. Self-production of food on small plots of land accounted for a high proportion of their incomes. Prior to the famine such production sustained a vigorous, rapidly growing population.<sup>9</sup> But that system had tragic consequences.

Population pressure in rural Ireland caused land prices to rise earlier in the 19th century. And

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<sup>9</sup>The introduction of potatoes into Europe in the 16th Century was hastened by rumors of aphrodisiac properties (Salaman, 1990). There is little doubt that potatoes have been instrumental in population growth at many times and places, though not for this reason. They have extraordinary nutrient value for humans (Heiser, 1990).

declining food prices after 1825 reduced farm wages and made it desirable for rural folk to economize further on food. The land economies afforded by the immense yield per acre of potato cultivation account for the increasing concentration and specialization of potatoes in rural diets immediately prior to the famine. The low income levels of these people, their self-sufficiency and lack of transferrable wealth, and the huge losses they suffered from declining potato productivity all worked to shut down the market for imported seed crop. And their prior self sufficiency in food and lack of financial wealth made it impossible to import much of anything else.

### **V. The Elasticity of Demand for Potatoes**

Quantitative information on potato consumption is very sketchy in the years surrounding the famine. For a large population, the enormous fraction of total food intake accounted by one source is without parallel. Perhaps the reason why so many of the Irish did not diversify their food consumption lies in the statements above. Beyond that, their food behavior raises interesting questions about risk aversion, interproduct substitution, and accounting for tastes, none of which can be addressed here.

Demand is more inelastic the smaller the degree of substitution with other goods. In addition, the short-run of supply of other food crops in Ireland was inelastic, itself caused by investment delays due to false expectations about future growing conditions, and by long-term land tenure contracts that constrained farm workers and small holders from assembling larger parcels of land needed to produce more land-intensive alternative crops. The large budget share accounted for by potatoes works in the other direction, but the force of habits and the unexpected character of the blight surely were more important initially.

The demand for potatoes in Ireland was much more elastic in the longer term, for more important reasons. Consumption fell along with production, not only because per capita consumption fell, but also because the famine reduced population size by so much. Post-famine average acreage fell to one-fourth of its pre-famine level. Since productivity per quality-constant acre declined by half and low quality land was

abandoned for potato cultivation, long-run production declined by at least a factor of 4. Price increased by a factor of 2 over the long-haul, so the implied long run elasticity of demand is more than -2.0. However, income also dropped and potatoes are inferior goods, so perhaps -2.0 is an upper bound on the long-run price elasticity of aggregate demand.

#### **A. Derived Demand for Potatoes as Feed**

Human consumption was the main source of demand for potatoes, but not the only one. Bourke (1993) estimates that one-third of the crop was eaten by livestock (mainly swine) in the prefamine period. Average daily intake per pig was slightly larger than per capita human consumption. A substantial amount of aggregate pig production was carried out among the same small holders who constituted much of the potato culture.<sup>10</sup> They converted self-production of potatoes into a cash crop by feeding some of them to pigs. Landlords did not share the gross proceeds in this business and the 100 percent marginal return to tenants clearly encouraged pig production (e.g., like “private plots” in the old Soviet collective agriculture).

It is interesting that pigs also are both consumption and capital goods (Rosen, et. al., 1994). The derived demand for animal-feed potatoes tends to be larger than for human consumption because there are additional possibilities for intertemporal adjustments of animal stocks. When feed is dear, breeding stock can be sold off or directly consumed. Crop is released for human consumption, though substitution is limited because animals eat lower quality varieties. Animal stocks are replaced later. More females are bred and less are consumed when feed is more plentiful and costs are smaller. Prior to the great famine, pig stocks commonly were observed to fall in years of potato crop shortage. Pig production served a natural buffer-inventory function for marginal farmers and tenants. It was a natural way to organize production to accommodate year-to-year variations in potato output.

Pig stocks were some 55 percent smaller in 1847 than at the agricultural census of 1841. Year-by-

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<sup>10</sup>It has been often noted that pigs were part of the rural family, as it were, an observation that still applies in rural areas of many poor countries today.

year data are not available, but it seems probable that these adjustments tempered some of the human distress caused by crop failure. Spotty export records indicate that pig and cattle shipments were unusually high in 1847 compared to 1835, the closest earlier year for which records are available. Notice that the principle of comparative advantage applies to the rationality of exporting animals for cash rather than eating them: the proceeds could be used to purchase cheaper substitutes, such as Indian Corn, which was imported in Ireland during the famine, but hardly in sufficient quantity.<sup>11</sup> It is probable that large numbers of pigs also were directly consumed. Of course these buffers and substitution possibilities are greater for transitory shocks than for permanent ones. They would have been more important in 1845-6 than later, but the detailed data are not available to tell.

Henry Schultz (1938) estimated the elasticity of demand for potatoes as  $-0.65$  in the U.S. during 1875-95. Potato budget shares for the average 1840 Irish consumer would have been larger than for the average 1875 American consumer, tending to raise the elasticity. Fewer available food substitutes tends to lower it. No direct estimates of the demand elasticity of potatoes for animal feed are available from any source. The stock of pigs in Ireland probably fell by more than 50% during the period when the price of potatoes tripled. Use of substitute feeds would have reduced potato feed demand by more than 50%, so a lower bound for the arc-elasticity of feed demand is in the range  $[-1/6, -1/3]$ . Since alternative feeds were in such limited supply it is implausible that feed demand was much more elastic than this.

## VI. The Elasticity Threshold in Ireland

Though the actual data suggest a long-run elasticity of around  $-2$ , much of that is made up of huge demographic changes in the consuming population. Given the cottage industry nature of production, a

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<sup>11</sup> Much has been made of the exports of grain and other foods from Ireland to England during the period (Sen, 1981), without recognizing the comparative advantage argument that with substantial adjustment costs it would pay to maintain production of high quality items for export and import lower priced, lower quality foodstuffs. On this important point, see O Grada (1995).

family's perceived per capita demand elasticity might be more relevant for market dynamics in figures 1 and 3. It was shown in equation (1) that demand has to be more inelastic than  $1-r/g$  for perceived target seed stocks in figure 3 to actually increase when  $g$  falls. In the pre-blight period  $g$  was 6.5 and in the post-blight period it was closer to 3.0. An estimate of the rate of interest is needed to calculate the threshold value for  $\eta$ .

We proceed by an indirect route. Begin with the fact that interest rates in rural areas of poor, undeveloped countries are high: 30% real rates are not unusual. O Grada (1995) calculates that the standard of living in pre-famine Ireland was approximately the same as that of Egypt today, so the effective interest rate for subsistence farmers there must have been large.

Mokyr (1983) describes an active loan market in rural Ireland. After all, potatoes stored for only 10 months, and the two summer months between the end of the storage period and the initial new harvest were hard and hungry, year-in and year-out. No systematic data on interest rates and defaults are available. However, there are remarkably large seasonal variations in potato prices (see graphs). An estimate of the interest rate can be backed out of O Grada's (1993) seasonal price numbers using elementary inventory theory.

Upon harvest, potatoes were stored in large holes dug below the frost line and covered to protect them from seepage and moisture. Ignoring noninterest costs of storage, if a farmer willingly held potatoes for ten months, the usual arbitrage condition requires that the relative price at months  $t$  and  $t+\tau$  satisfy  $p_t = [(1 - \delta)/(1+r_\tau)]p_{t+\tau}$ , where  $r_\tau$  is the  $\tau$ -month interest rate and  $\delta$  is the  $\tau$ -month depreciation rate. Seasonal peak prices are about twice as high as harvest prices in O Grada's data, so  $p_{t+\tau}/p_t = (1+r_\tau)/(1-\delta) \approx 2$ .<sup>12</sup> Potatoes store rather well if kept in a cool, dry place, but there is shrinkage due to moisture and pests. Depreciation of stored potatoes under modern conditions is about 15%. Given the great dependence on potatoes, it is hard to

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<sup>12</sup> O Grada's (1993) data shows different seasonal variation in prices before and after the famine. The famine-induced migration into cities increased transactions volume in potato markets, so the price data probably are much better after 1848 than before. In addition, perhaps the seasonal changed as the city trade increased and the market became more professionalized.

imagine that the depreciation rate was larger than 30% in Ireland of the 1840's. In that case the formula implies an interest rate of about 30%. If  $\delta$  was smaller than 30%,  $r$  must have been larger. But if direct costs of storage were significant,  $r$  would be smaller.

Using  $0.3 \leq r \leq .5$ , the threshold value  $1 - r/g$  is estimated to be at least .95 before the famine and 0.9 or more after the famine. Therefore it is possible that the (ex ante) per family elasticity of demand for potatoes in 1840's Ireland was below the critical threshold value of .6 and that excess savings of seed stock inventories played some role in the latter part of the Famine. However, given the high interest rate, these kinds of forward looking adjustments could not have been very large. The initial error in mistaking a permanent decline in productivity for a temporary one is far more important.

## VII. Conclusion

As pathological as it was, the main production aspects of the Irish Famine can be analyzed in fairly conventional economic terms. Adapting a sophisticated dynamic model does a tolerable job of explaining the main facts and behavior. This application is possible because the potato technology is so simple and because the event that precipitated it is transparent in hindsight. Most empirical dynamic economic models require specifying elaborate unobserved structures for exogenous driving forces. Issues of that kind do not arise here.

The most drastic consequences of the blight were caused by tragic miscalculation that a permanent shock was transitory, as previously emphasized by Mokyr (1983) and O Grada (1993). This mistake provoked over-saving by a population in dire circumstances and delayed reorganizations of agricultural production to more productive crops. In lesser part, the famine may have been prolonged by the need to conserve seed stocks after its permanent nature was recognized. However, the high discount rates in the effected population, made even higher by starvation, suggests a very limited role there. Instead, potato cultivation was scaled way back.

Were Irish farmers "rational"? Obviously not, in some general over-riding sense. But in more

limited economic terms and considering their extreme diets, who is to say that they did not act in their perceived best interests *given the information that was available*? The economics on these conditional rationality terms works quite well. Perhaps the Knightian distinction between risk and uncertainty is relevant here. Decisive scientific identification of a blight as the true cause of the productivity decline only came years after it's first occurrence. The huge effects of agricultural science on agricultural productivity in general occurred decades later.

The size and correlation of the disturbance, and the largely cashless, self-production economy in which the potato culture thrived made the blight an uninsurable event. Its scale was too vast and too widely distributed, equivalent to a sudden 50% percent or more increase in the price of food for at least a third of the population. This is huge by any measure. Surely even today the consequences of an unexpected 25 -35 percent decline in the standard of living for more than one third of a population living close to subsistence would be drastic.

If the famine was insurable, in principle, at the level of the world economy, limited economic power of States in the 19th Century, and the insularity of Irish small-holders and tenants constrained the ability of the world economy to react to the crisis. Ideology probably did as well. But even modern insurance arrangements for famines, such as they are, largely depend on gifts of concerned donor countries rather than on secure contracts. It is not difficult to imagine why this is the case.

Much has been made of the lack of response by England to the Irish plight. Though these issues are far beyond the scope of this analysis, the vast scale of the event always must be borne in mind. It greatly limited the possibilities. No doubt England could have done more by way of relief, but how could London have known more about the character of the disturbance than those directly involved? By what powers could Parliament have guessed the blight to be permanent, when apparently the prevailing opinion, conspicuously revealed by behavior, initially held it to be temporary? And though England was wealthier than Ireland, the Irish population was larger (the population in Ireland today is smaller than in 1840). The decline in Irish

income was enormous. Massive aid would have been necessary to avert the catastrophe, probably on a scale never seen in history so far.

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