Potato Paradoxes

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Price and quantity data prove that Irish potatoes in the 1840s were not Giffen goods. Intertemporal trade-offs required by the fact that a sizable fraction of the potato crop is needed for seed crops can produce unusual market dynamics. The Irish experience is well described by a normal demand model in which a permanent decline in the productivity of seed potatoes was at first mistaken as a transitory crop failure. These mistakes provoked ‘‘oversaving’’ of seed crop in a population in dire circumstances. With the benefit of hindsight, consumption of seed crop capital was warranted. Erroneous expectations of potato productivity by growers delayed necessary agricultural adjustments and contributed to the catastrophe later on.

I. Introduction

Potatoes are very interesting goods. They have been an important food staple in the world since the eighteenth 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 one of the worst famines in recorded history. And because of their importance in the diets of many poor people, potatoes are a leading practical example of an inferior good, if not

I am especially indebted to Cormac Ó Gráda for advice and information on the famine and for criticism of an initial draft. Mokyr (1983), Ó Gráda (1989, 1993), and Bourke (1993) are the essential economic sources and analysis of the Irish famine. I have used all of them extensively, though not always with detailed attribution. Thanks also go to Gary Becker, D. Gale Johnson, Stanley Engerman, and Robert Lucas for discussion and comments. I take full responsibility for error and interpretations.

[*Journal of Political Economy*, 1999, vol. 107, no. 6, pt. 2]

a 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 potato buds (or ''eyes'') are replanted for next year's crop. Seed crop capital is an important component of total production in modern conditions, depending on climate, soil quality, and agricultural technology. In parts of Russia today, seed potatoes may account for as much as 25 percent of the crop. In the United States it is 7–9 percent. It probably was on the order of 15 percent in nineteenth-century Ireland during the famine era (Bourke 1993).

Adjustments in seed stock inventory 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 the quantity supplied decreases, consumption can increase even if demand is downward-sloping, an effect that might be wrongly confused with the Giffen paradox.

Near 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 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. Pathologies are interesting to study when the main causal elements dominate everything else. The blight was an entirely exogenous shock that overwhelmed all other factors affecting demand and supply of the major food crop in Ireland. Section II sketches an abstract economic model of the potato market. Later sections interpret some of the Irish data in its light.

The major outlines of the disaster are well described by a 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. 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. It is clear in hindsight that in the first year seed stocks should have been eaten instead. Since potatoes were so important in the diets of rural dwellers and smallholders, gross oversaving by people in such dire circumstances had catastrophic consequences later on. And it delayed substitution to other crops that could have eased, though hardly eliminated, the suffering.

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

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

with $g > 0$. Potatoes can be stored for no more that 10 months, so seed crops withheld from final consumption are all that is available for producing output in following years. In nineteenth-century Ireland, the 15 percent seed/output ratio meant that one seed potato produced about $1/.15 = 7.5$ potatoes next season, implying $g = 6.5$. In the United States today it is 12–15 to 1, so g is in the 11–14 range. Total output is used for seed crop and consumption:

$$Q_t = S_t + C_t. \tag{2}$$

B. Behavioral Relationships

To simplify, assume no intertemporal elements in consumption demand from year to year (but see below on seasonal variations). Then market demand is $C_t = C(p_t)$, where p is the price of the good. Supply is determined by farmers' decisions either to sell their crops for immediate consumption or to hold some of them over the season for seed, replanting, and selling or planting crop next year. When labor inputs are ignored,[1] the return from selling is the current price

[1] Labor inputs are important for potatoes. Consider eq. (1) as a reduced form in which other inputs have been optimized out 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. Because it is so simple, I choose to model rising supply price as arising from increasing marginal holding costs rather than from diminishing returns directly, but they are (approximately) equivalent for local dynamics (see below).

p_t. Withholding a unit of stock and replanting it produces $1 + g$ units next season. They can be sold for expected price p_{t+1}. Let $k(S)$ be the direct marginal cost of planting and storage, with $k'(S) \geq 0$, and let r be the rate of interest. With $G = (1 + g)/(1 + r)$, 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

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

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

The intertemporal arbitrage condition in (3) is one restriction on the observed paths of stocks and supply prices. When the demand curve, production function, and storage-consumption-production identity are combined, stock-flow dynamics imply another restriction:

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

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 $p_t = p_{t-1} = \cdots = \mathbf{p}$ and $S_t = S_{t-1} = \cdots = \mathbf{S}$. Equation (3) becomes

$$\mathbf{p} = \frac{k(\mathbf{S})}{G - 1}. \tag{5}$$

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. Renewal implies that this rate of return, $G - 1 = (g - r)/(1 + r)$, is positive. 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:

$$\mathbf{S} = \frac{C(\mathbf{p})}{g}. \tag{6}$$

Equation (6) defines a decreasing curve in the (p, S) plane if the good is normal and an increasing or backward-bending curve if it is Giffen in part of its range (see figs. 1 and 2).

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

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

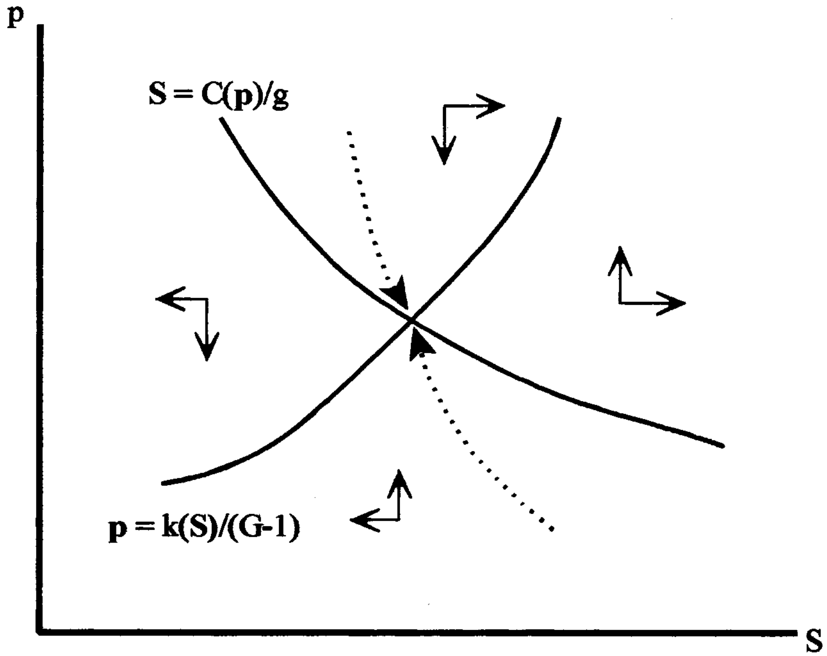

FIG. 1.—Normal transient dynamics

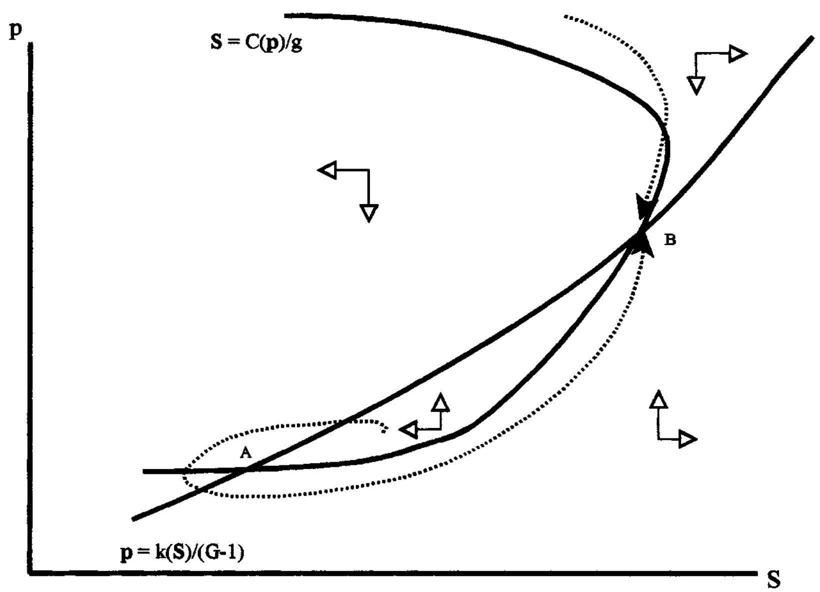

FIG. 2.—Giffen good dynamics

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, with (6), equation (4) becomes

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

The term $S_{t+1} - S_t$ is positive and stock is growing for any pairs (p, S) that lie to the right of the curve defined by (6). Stock falls for (p, S) pairs that lie to the left of it. The phase arrows point in the corresponding directions.

The motions defined by (7) and (8) for any initial conditions are described by familiar saddle-point dynamics in the (p, S) plane.[2] When the boundary condition that the discounted value of expected future crop is finite is applied, 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. *Transitory* (one-period) shocks have important spillover effects on future periods. For instance, if a temporary one-year crop failure reduces 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-term consumption under normal conditions. 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-state levels. Recovery is drawn out in time. Conversely, if a temporary shock increases initial stock above its long-run equilibrium level, the unexpected bounty causes price to fall to encourage extra consumption and gradually drive stocks back down to their normal steady-state levels in subsequent years. The speed of the subsequent adjustments varies in proportion to g and r.

Figure 2 depicts a Giffen good, where quantity demanded is increasing in price in the relevant range. Here the **p** curve in equation (5) is upward-sloping for low values of p and S because high prices provoke greater consumption. There are two kinds of equilibria in

[2] Linearizing $k(S)$ and $C(p)$ in the neighborhood of the steady state yields a pair of linear difference equations. In a stable system 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 seen only in the forward-looking part of the particular solution. Notice that in this system, it makes no difference whether the **p** manifold is increasing because of rising inventory costs or directly diminishing returns, as asserted above.

this case. One is stable and the other is unstable. If the Giffen effect is so strong that the **p** curve is flatter than the **S** curve in figure 2, the phase arrows near that intersection reflect the fact that the associated linear system has explosive cycles (complex eigenvalues with modulus greater than $1 + r$). The market is Hicksian unstable (and the implied cycles are inefficient). This node is labeled *A* in figure 2. The equilibrium is stable only when the rising **S** curve cuts the **p** curve from below (point *B* in the figure). Here the stable arrows in the neighborhood of equilibrium slant in the opposite direction compared to 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.

D. Changes in Supply and Demand

Permanent shocks to demand or supply shift both the steady-state loci in figure 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** curve in figure 1 upward and to the right. If seed stock is too small when the shock occurs, price initially rises to discourage consumption and encourage holding more crop for seed. The high price gradually falls thereafter to its higher steady-state value as consumption increases. That the quantity supplied to the consumption market for a normal good 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 experiment more relevant for the famine is an unanticipated but thereafter permanent shock to supply. Suppose that the productivity factor g falls unexpectedly and remains smaller forever. Depending on initial conditions, demand elasticities, and other parameters, a permanent negative supply shock can cause price to actually fall initially, even if demand is normal. Such an event might be confused with a Giffen effect, but it is just another odd economic implication of what can happen when output is both a consumption good and a capital good.[3]

[3] Alfred Marshall mentioned grains as possible Giffen goods, not potatoes. Note that seed stock requirements for grains in the nineteenth century were much larger than they are today. For example, in the 1840s, seed stocks amounted to about 15 percent of wheat crops, so these same considerations apply to grains. Unusual dy-

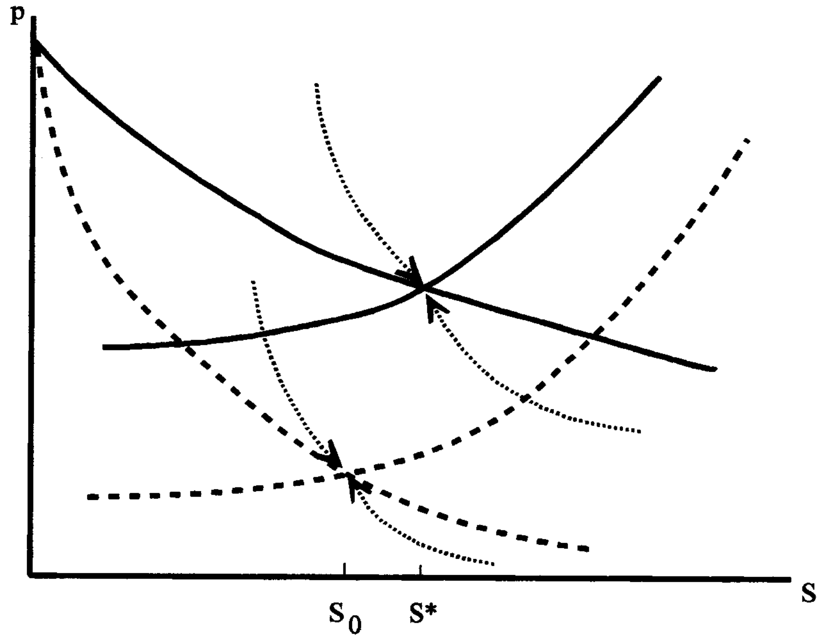

FIG. 3.—The effect of a permanent productivity shock

A decline in g reduces the return to cultivation in equation (5) and raises the minimum long-run supply price $k(\mathbf{S})/(G-1)$. The **p** locus shifts up, as in the solid upward-sloping curve in figure 3. But sustaining any given level of consumption in the long run requires larger seed stock inventories because each seed has lower productivity: $C(\mathbf{p})/g$ increases and the **S** locus shifts to the right (the solid downward-sloping curve in fig. 3). 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, initial price falls to induce capital consumption. Whether target inventories rise or fall depends on the elasticity of demand for the good.

To see this last point, define $\eta = (d \log C)/(d \log p)$ as the price

namics caused by decisions about seed inventory do not necessarily imply Giffen goods.

elasticity of demand and ϵ as the price elasticity of long-run supply. Comparative statics on (5) and (6) yield

$$\frac{\partial \log \mathbf{p}}{\partial g} = -\frac{[1 - (r/g)] + \epsilon}{\epsilon(g - r)[1 - (\eta/\epsilon)]} < 0 \tag{9}$$

and

$$\frac{\partial \log \mathbf{S}}{\partial g} = -\frac{\eta + [1 - (r/g)]}{(g - r)[1 - (\eta/\epsilon)]}. \tag{10}$$

As shown above, market stability requires $1 - (\eta/\epsilon) > 0$.

Equation (9) shows that long-run price always decreases in g. The sign of (10) is ambiguous. The derivative $(\partial \log \mathbf{S})/\partial g$ is positive or negative according to whether the elasticity of demand exceeds or falls short of $1 - (r/g)$. If demand is sufficiently elastic, **S** falls when g falls, and steady-state consumption decreases so much that steady-state inventories decrease in spite of the fact that more seed crop is required to produce any level of output. When demand is sufficiently *inelastic*, steady-state seed inventories *increase* when g falls. Since consumption does not fall so much, the smaller productivity of seed requires a larger seed stock to sustain it. In this case, intertemporal 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. In that case, 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 toward the end of 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 as significant excess (age-adjusted) mortality experience, did not occur prior to 1845 (Ó Gráda 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 leave no doubt that the blight was an entirely unexpected event. It was one of the most unfortunate ‘‘natural experiments’’ in modern history. As difficult as it is to imagine today, on the eve of the famine, per capita consumption of potatoes is reliably estimated to have averaged 9 pounds (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 lingering, permanent effect of the blight on the productivity of potato cultivation in Ireland was the true cause of the Great Famine.[4] Much current interest in the famine revolves around how government policies responded to the shock, which will not be discussed here. For analysis of the market behavior that is the focus of this paper, the blight-induced ‘‘technology shock’’ was the proximate cause of food shortages and famine 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 was no significant decline in planting 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 postfamine eras, implying that the blight reduced permanent (nineteenth-century) productivity by about 50 percent.[5]

The time series for potato prices at the Waterford market collected by Solar (1989) appear in figure 4.[6] Since so much of the potato crop was self-produced and self-consumed by cottiers and

[4] To put the disaster in proper perspective, the famine killed at least 12 percent of the population over a three-year period. Another 6–8 percent migrated to other countries. In terms of the percentage of population affected, the 1845–48 famine is one of the largest ever recorded. Other famines have killed more people in total because the affected populations were larger, not the percentage of exposure. For instance, the 30 million or more people who perished in the Chinese famine of 1958–62 were 5 percent or 6 percent of the population. In comparison to other disasters in living memory, World War II casualty rates (military and civilian) in all countries except Yugoslavia were much smaller than 12 percent (Wright 1965).

[5] Pre- and postfamine 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 are more secure from relative price data than from aggregate quantity data.

[6] I am indebted to Peter Solar for allowing me to reproduce his data. The figures shown pertain to the Waterford market. Solar’s prices from the Belfast market and Ó Gráda’s (1993) time series from the Dublin market are similar to what is shown in fig. 4*a*.

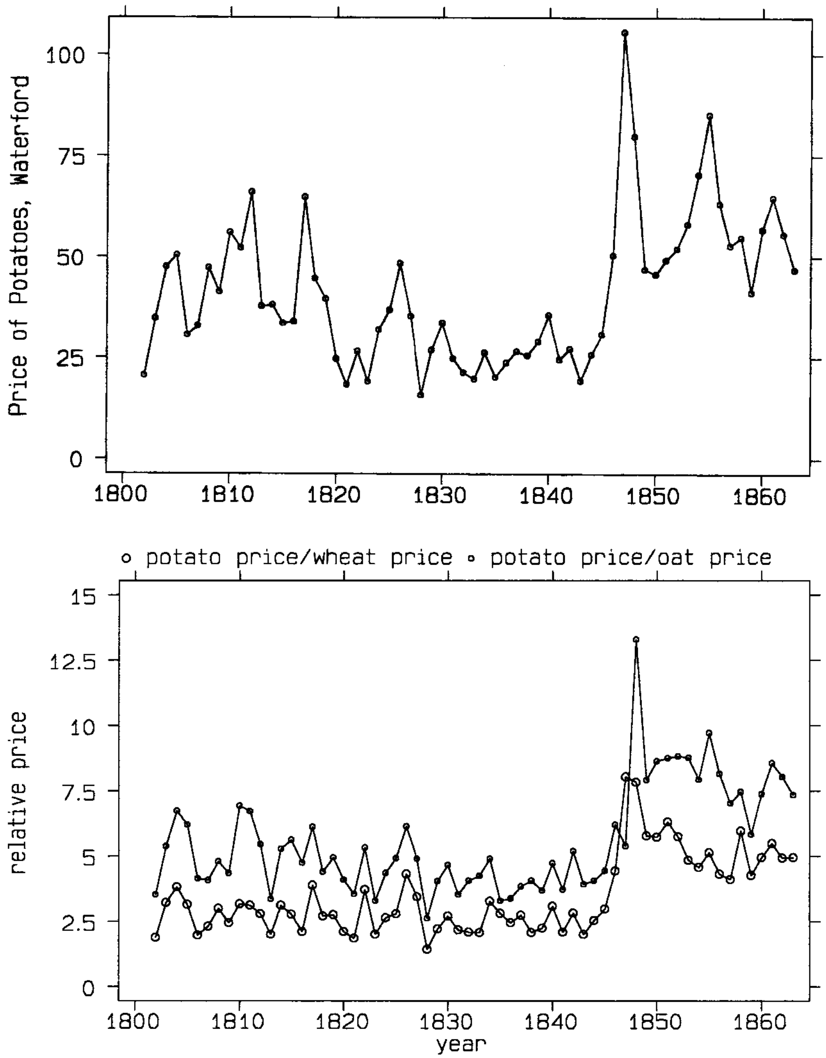

FIG. 4.—*a*, Irish potato prices per hundredweight in the Waterford market. *b*, Prices of potatoes at Waterford relative to wheat and oats.

smallholders, annual time series of potato production are not available: only production shortfalls in the famine years and the long-term trends in acreage have been carefully documented. Figure 4*a* shows that average annual prices per pound in urban markets increased more than threefold during the famine years in comparison to the prefamine period. At the same time, output and consumption fell by large proportions (50–80 percent). The price increase was sharply concentrated in the period 1846–48. Prices declined to their postfamine, post–productivity shock, steady-state level fairly soon thereafter. The same general story is shown in the relative price comparisons of potatoes with wheat and oats. The level of prices for wheat and oats (not shown) also rose during the famine period, but not by so much. The increase in relative price probably reflects the effects of substitution in demand, since it is known that wheat and oat products (as well as dairy and meat products) became more important in Irish diets after the famine period. Notice also that there is a downward trend in prices of potatoes before 1845, no doubt reflecting productivity improvements from the introduction of higher-yielding varieties that more than offset the effects of diminishing returns as total output increased prior to 1845.

Applying the model to these data requires auxiliary hypotheses about producer expectations. These expectations cannot be determined with great precision, but historical data suggest a reasonably simple approximation. 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 from that. Their grossly inaccurate anticipations had terrible consequences.

The dynamics are well described by a two-stage version of the model. In the first stage, growers were grossly mistaken in judging the 1845 shock as transitory rather than as permanent. This interpretation is supported by the observation that planting in 1846 remained at its prefamine level. The second stage is the realization that potato productivity had in fact fallen permanently after the abysmal harvest of 1846. The transient dynamics of figures 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 in the following year, the available data are entirely consistent with figure 1, but not with figure 2. Given the 50 percent shortfall in output 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 rise to discourage consumption and sustain a constant investment in seed stock for 1846 out of a much smaller harvest. If, in normal years, 15 percent of the crop was held over for planting, in 1845, more like 30 percent of output was held back for planting the following year. This is a remarkably high rate of saving for the future under such drastic current conditions.

Potatoes in Ireland were inferior goods, but they were not Giffen goods. A recent paper by Davies (1994) incorporated survival constraints into preferences to rationalize Giffen goods. The idea is that when a consumer is close to subsistence and specializes food consumption on one item, a reduction in its price frees up income for other purposes. It liberates the consumer from binding nutritional constraints and allows less basic, ''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 fact is that the survival constraint (especially in 1846 and 1847) was not binding. That in the first year price rose drastically and consumption fell proves without a shadow of doubt that potatoes were not Giffen.[7]

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 potato planting in 1846 would have been much smaller. Growers 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, sometime after the second disastrous crop failure of 1846. The blight-induced productivity decline shifted the perceived steady-state curves from the dotted lines to their true values—the solid lines in the figure. At the aggregate level, steady-state stocks and consumption decreased dramatically, mostly caused by the extraordinary deaths and emigration to other countries. 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, as depicted in figure 3. But this last effect is not identified with the data at hand, because whether growers considered demand to be elastic or inelastic, production shortfalls would cause price to rise and consumption to fall.

Before I examine 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 closed. Were potatoes freely traded among countries and had the blight

[7] Earlier, Dougan (1982) analyzed the unusual dynamic implications of Giffen goods using the static Hicksian stability framework. This analysis is a natural extension of his.

been greater in Ireland than elsewhere,[8] imports and intertemporal rearrangements of world consumption across countries could have made up the Irish shortfall. The blight was not nearly so extensive in other European countries (though their exposure was much smaller as well), so the enormous price increase observed in Ireland implies substantial limitations on the international potato trade. Since potatoes consist mostly of water, transportation costs per unit of nutrient value are large compared to more commonly traded foods such as grain. The high land transport costs of the mid-nineteenth 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 crop is more interesting economically. Potatoes are so productive as capital that seed crop requires a much smaller volume of trade and involves lower costs per unit of value compared to potatoes for consumption. In fact high-yielding new varieties often were exported. The Irish potato was known throughout the world and remains so today. 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. Yet during the famine years, there is no evidence of significant imports of seed potatoes. The Irish potato economy was essentially closed.

The standard economic arguments for restricted trade and limited intertemporal substitution revolve around capital market imperfections or, in more fashionable terminology, "liquidity constraints." The people who suffered most from the famine were rural dwellers: smallholders, tenants, and laborers operating largely in a cashless, subsistence economy. Self-production of food on small plots of land accounted for a very high proportion of their incomes. Most potatoes were produced and consumed by families on tiny plots of land. Prior to the famine, such production sustained a vigor-

[8] The blight was endemic in South America, where the potato originated, but Europe was blight-free because *p. infestans* could not survive the long sailing voyage. The shorter steamship voyage changed all that (McNeill 1976). It is ironic that much later the blight destroyed the South American crop, and blight-resistant varieties imported from Europe are grown there today. Nothing is left of the native South American varieties (Heiser 1990), though strains of the blight are still active.

ous, rapidly growing population.[9] But that system had tragic consequences.

Population pressure in rural Ireland caused land prices to rise earlier in the nineteenth century. And 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 help but do not fully 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 transferable 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 only one source is without parallel. Perhaps a reason why so many of the Irish did not diversify their food consumption lies in the statements immediately above. Even so, most subsistence societies in which self-production of food has occurred on small plots of land have not been so monocultural. Beyond that, their food behavior raises important questions about risk aversion, interproduct substitution, and the nature of tastes, none of which are addressed here.

Demand is more inelastic the smaller the degree of substitution with other goods. In addition, the short-run supply of other food crops in Ireland was inelastic, itself caused by investment delays due to false expectations about future growing conditions, and perhaps by long-term land tenure contracts that constrained farm workers and small holders from quickly assembling larger parcels of land needed to produce more land-intensive crops for self-consumption. 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

[9] The introduction of potatoes into Europe in the sixteenth century was hastened by rumors of aphrodisiac properties (Salaman 1949). 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).

with production, not only because per capita consumption fell, but also because the famine reduced the size of the population by so much. Postfamine average acreage fell to one-fourth of its prefamine 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 four. Price increased by a factor of two 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 smallholders who constituted much of the potato culture. They converted self-production of potatoes into a cash crop by feeding some of them to pigs.[10] 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).

Pigs also serve as both consumption and capital goods (Rosen, Murphy, and Scheinkman 1994). The elasticity of derived demand for potatoes fed to animals 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 is 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: fewer females are slaughtered, and more are bred when feed is more plentiful and costs are smaller. Prior to the great famine, pig stocks commonly were observed to fall in years of a shortage of potato crop. Pig production served a kind of buffer inventory function for marginal farmers and tenants. It was a natural way to organize production to accommodate year-to-year fluctuations in potato output.

Systematic time series on pig stocks are unavailable, but it is known

[10] It often has been 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. If in the United States pigs are ''corn with legs,'' in Ireland of that time pigs were potatoes with legs. Longfield (1834, pp. 249–56) presents a lucid early analysis.

that the Irish stock was 55 percent smaller in 1847 than at the agricultural census of 1841. Though data for the years in between are missing, 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 into Ireland during the famine, but hardly in sufficient quantity to avoid starvation.[11] 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 1845–46 than later, but the data are not available to tell.

Schultz (1938) estimated the elasticity of demand of potatoes for human consumption as −.65 in the United States during 1875–95. Potato budget shares for the average 1840 Irish consumer would have been much larger than for the average 1875 American consumer, tending to raise the elasticity. Fewer available food substitutes tend 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 percent during the period when the price of potatoes doubled. Use of substitute feeds would have reduced demand for potato feed by more than 50 percent, so a lower bound for the arc elasticity of feed demand is in the −⅓ to −½ range. 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 changes in the size of the consuming population. Given the cottage industry nature of production, a family's perceived per capita demand elasticity might be more relevant for market dynamics in figures 1 and 3. Equation (10) shows 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 preblight period, g was 6.5; in the postblight period, it was closer to

[11] Much has been made of the exports of grain and other foods from Ireland to England during the period (Sen 1981). But note that the principle of comparative advantage applies. With substantial adjustment costs, it would pay to maintain production of high-quality items for export and import lower-priced, lower-quality foodstuffs for personal consumption. On this important point, see Ó Gráda (1995).

3.0. An estimate of the rate of interest is needed to calculate the threshold value for η.

I proceed by an indirect route. Begin with the fact that interest rates in rural areas of poor, undeveloped countries are high: 30 percent real rates are not unusual. Ó Gráda (1995) calculates that the standard of living in prefamine 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 prefamine rural Ireland. Since potatoes store for 10 months, 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, Ó Gráda (1993) documents large seasonal variations in potato prices. An estimate of the interest rate can be backed out of seasonal price numbers using elementary inventory theory.

At harvest, potatoes were stored in large holes dug below the frost line and covered to protect them from vermin, seepage, and moisture. Direct costs of storage (labor and the like) were small and are ignored. If a farmer willingly held potatoes for 10 months, the usual arbitrage condition requires that the relative prices at months t and $t + \tau$ satisfy $p_t = [(1 - \delta)/(1 + r_\tau)]p_{t+\tau}$, where r_τ is the τ-month interest rate and δ is the τ-month depreciation rate. Seasonal peak prices often were twice as high as harvest prices. In that case, $p_{t+\tau}/p_t = (1 + r_\tau)/(1 - \delta) \approx 2$. 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 percent. Given the great dependence on potatoes, it is hard to imagine that the depreciation rate was larger than 30 percent in Ireland of the 1840s. In that case the formula implies an interest rate of about 30 percent. If δ was smaller than 30 percent, r must have been larger; if direct costs of storage were significant, r would be smaller. Finally, there is a fair bit of year-to-year variation in the size of seasonal patterns, which adds even more noise to the estimate of r.

When $0.3 \leq r \leq .5$, the threshold value $1 - (r/g)$ is estimated to be at least .95 before the famine and .9 or more after the famine. Notice that this threshold value is not very sensitive to the interest rate because g is so large. Since the threshold value is near unity, it is possible that the (ex ante) elasticity of demand for potatoes per family in 1840s Ireland was below the critical threshold value and that excess savings of seed stock inventories played some role in the latter part of the famine as well as in the first year. However, given a high discount 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 was far more important.

VII. Conclusion

As horrific as it was, the main production aspects of the Irish famine can be analyzed in fairly conventional economic terms. Adapting a familiar dynamic model does a tolerable job of explaining the main time-series data on the consumption and production of potatoes. This application is possible because potato technology is so simple and because the event that precipitated it is so transparent in hindsight. Most empirical dynamic economic models require greater elaboration and detailed technical assumptions about unobserved exogenous disturbances. Issues of that kind do not arise here because the timing of the blight's arrival is precise and its consequences eclipse everything else.

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 Ó Gráda (1993). This delayed reorganizations of agricultural production to more productive crops. These faulty perceptions perhaps are understandable, if not "rational," given the information that was available to people in those days. Potatoes had supported a large and growing population for many years with relatively little risk. Decisive scientific identification of blight as the true cause of the productivity decline came only years after its first occurrence. The huge effects of agricultural science on agricultural productivity in general occurred almost a century later. The new point added by this analysis is that the mistake provoked oversaving by a population in dire circumstances, certainly in the first year and possibly in later ones as well. The famine may have been prolonged by a perceived need to conserve seed stocks even after its permanent nature was recognized. However, the high discount rates in the affected population, made even higher by sickness and starvation, suggest a limited role there. Instead, potato cultivation was scaled way back.

The adverse consequences of the potato blight were heightened by the extraordinary importance of potatoes in the self-production and consumption of food among large rural Irish families. It caused the equivalent of a sudden 50 percent or more increase in the price of food for at least one-third of the population. That translates to a massive 25–30 percent unexpected decline in their standard of living. An event of that scale would cause misery even in a rich population.

Since the Giffen paradox is not useful for understanding the Irish experience, is it asking too much for future writers of elementary texts to find another example? Fictions have no place in the teaching of economics. If any paradox remains for understanding the economics of the famine, it is how human fertility decisions, population pressures, and the social and economic system of Ireland at that time encouraged such large families, such specialized personal food production, and such shockingly undiversified diets. Perhaps this is a case in which economic analysis is limited by not being able to account for tastes.

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