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Environmental effects of intensification of agriculture: livestock production and regulation

Ujjayant Chakravorty,[1] **Donna K. Fisher,**[2] **and Chieko Umetsu**[3]

[1] Department of Economics, University of Central Florida, PO Box 161400, Orlando, FL 32816-1400, USA
[2] School of Economic Development, Georgia Southern University, PO Box 8152, Statesboro, GA 30460, USA
[3] Research Institute for Humanity and Nature, 457-4 Kamigamo-Motoyama, Kyoto 603-8047, Japan

Abstract This article deals with the relationship between industrialization of agriculture and the environment in developing countries. We specifically focus on livestock production and regulation. We develop a simple economic framework to demonstrate the effect of location on intensification of industrial activity in farming, and discuss this issue in the context of urbanization and economic growth in developing countries. Policy implications of the model are discussed in light of the experience of developed countries in regulating livestock pollution and other externalities. We argue that environmental problems from agricultural industrialization in developing countries may pose major challenges. In the case of livestock production, these are compounded by production intensity, high population densities in periurban and urban areas, and the generally lower public health standards. As the recent outbreaks of severe acute respiratory syndrome (SARS) and avian influenza epidemics in Asia suggest, the new era of globalization and the onset of a free world trade regime points to the urgent need for developing countries to install inspection and enforcement mechanisms that ensure product safety and quality, as well as minimize the adverse effects on the environment.

1 Introduction

It is universally known to observers of agricultural development that the structure of agriculture is rapidly changing both in developed and developing countries. These changes are being caused by economic development, growth in income and population, shifts in taste, as well as by supply side factors such as market deregulation, technological change, and limited availability of land and other scarce factors of production. These changes have not only affected the way business has been traditionally conducted on the farm, but are the cause of major environmental and public health impacts that have local and

global consequences. The recent outbreaks of SARS and avian influenza in Asia and their worldwide impacts are examples of the global repercussions of local health and environmental problems. The intensification of agricultural activities such as food and livestock processing in urban and semiurban lands has contributed significantly to the deteriorating environment in many developing countries.

These issues have serious ramifications for the complex relationship between agriculture and the environment as well as on agriculture's ever-increasing role in the economy as a sector that promotes and nurtures an environmentally sustainable way of life. There is a dearth of studies that examine the scope and extent of industrialization, and its effects on the environmental and natural resource base. In particular, because the industrialization of agriculture is taking place mainly in the developing countries, there is also very little systematic empirical evidence available. The past preoccupation with the "green revolution" has tended to obfuscate the growing seriousness of the problems generated by the "livestock revolution." Most available information is based on anecdotal evidence and isolated case studies. The problems are compounded by the fact that there is hardly any systematic regulatory supervision of agroindustrial activities in the developing world.

In this article, we review the major issues related to the industrialization of agriculture with a focus on livestock production. We then develop a simple von Thünen framework to address the issue of intensification of farming and its environmental implications. Given that much of the industrial evolution of agriculture in the developing world is heavily modeled on the developed country experience, we then draw from the experience of the developed countries. We conclude that problems from agroindustrialization in the developing countries may pose bigger challenges, given the intense population densities in periurban and urban areas and the generally lower public health standards prevailing in most countries.

The rest of the article is divided as follows. Section 2 overviews the nature and extent of agroindustrialization and its effect on the environment. Section 3 highlights the current state of intensive livestock production in the Asia-Pacific region, with a particular focus on beef and dairy cattle. Section 4 develops a theoretical model that explains intensification of input use in urban and periurban areas as well as allocation of land to alternative uses. Section 5 focuses on the environmental externalities from agroindustrialization. Specifically, the regulatory experience in the USA is discussed in light of conditions in the developing countries in Sect. 6. Finally, Sect. 7 concludes the article by outlining possible directions for policy reform in developing countries.

2 The problem of agroindustrialization

Hamilton (1997) defines the process of agroindustrialization, especially in livestock production, as: (1) the concentration of production into large units; (2) the increase in integrated or corporate, nonowner-operated facilities; (3) the geo-

Table 1. Total meat and milk consumption by region, 1965–2000

Region	Meat (million metric tons)					Milk and products (million metric tons)				
	1965	1975	1985	1995	2000	1965	1975	1985	1995	2000
World	83.4	114.7	152.0	203.3	232.1	242.6	303.0	380.7	432.3	473.4
Developed countries	58.6	79.7	93.9	98.3	101.6	178.6	215.2	246.4	249.2	258.6
Developing countries	24.8	36.0	58.1	105.0	130.6	64.0	87.8	134.3	183.1	214.8
Asia	14.3	21.4	39.4	78.1	97.3	38.8	52.6	85.4	128.2	152.5
Latin America and the Caribbean	8.0	11.6	15.9	26.0	30.8	19.6	29.2	37.6	50.8	56.3
Sub-Saharan Africa	2.9	3.5	5.0	5.8	6.8	6.6	8.4	13.3	15.5	17.4

Source: FAOSTAT 1997, 2006

Table 2. Per capita meat and milk consumption by region, 1965–2000

Region	Meat (million metric tons)					Milk and products (million metric tons)				
	1965	1975	1985	1995	2000	1965	1975	1985	1995	2000
World	25.1	28.3	31.6	35.9	38.4	72.93	74.7	79	76.5	78.2
Developed countries	56.9	70.7	77.4	76.2	77.2	173.6	191	203.1	193.1	196.5
Developing countries	10.8	11.9	16.1	24.1	27.6	27.8	30	37.3	42	45.4
Asia	7.7	9.2	14	22.9	26.5	20.9	22.5	30.3	37.5	41.5
Latin America and the Caribbean	32.3	36.4	39.9	54.7	59.7	79.2	91.8	94.6	106.8	109.3
Sub-Saharan Africa	12.4	11.7	12.3	10.9	11.2	28.6	28.1	33	29	28.6

Source: FAOSTAT 1997, 2006

graphic shift of production to nontraditional areas; and, (4) the increased use of hired labor or contract growers.

One of the most important aspects of agroindustrialization, often called the "livestock revolution," is the growth of meat and milk production relative to cereal. In the period between 1965 and 2000, consumption of meat in developing countries grew by 105 million metric tons (427%), while consumption in developed countries increased by 43 million tons (88%) (see Table 1). In 2000, per capita meat consumption in developed and developing countries was 77.2 and 27.6 kg/year, respectively. On the other hand, per capita consumption of milk and milk products in developed countries was 196.5 kg/year, while that in developing countries was only 45.4 kg/year (see Table 2). Given that meat and milk consumption levels in the developed countries are currently several times higher than in developing countries, and that there is likely to be an inevitable convergence in the standards of living and dietary patterns between these two groups of countries, these differential growth rates have given rise to a major increase in livestock production in the developing countries (Delgado et al. 1998).

This increase in demand for livestock products necessitates a change in the structure of livestock production from being dependent on surplus resources such as underutilized lands, pastures, and grasses with low opportunity costs in alternative uses, to an intensive use of limited resources such as land and vegetation. The cultivation of livestock in urban and periurban environments in close prox-

Table 3. Total stock of live animals in the world, 1965–2000

Animal	Animal stock (million head)				
	1965	1975	1985	1995	2000
Cattle	1009	1187	1259	1325	1315
Sheep	1030	1046	1119	1074	1053
Pigs	496	686	794	899	896
Goats	367	404	485	661	721
Buffalo	95	113	136	159	163
Chickens	4	6	9	13	14

Source: FAOSTAT 1997, 2006

imity to urban demand centers perpetuates severe environmental problems. The lack of any systematic regulatory and public health enforcement mechanisms in the developing countries further exacerbates these impacts. The dense packing of animals and people in the hinterlands of major urban centers leads to animal-borne diseases such as salmonella, *Escherichia coli* infections, and avian flu (Delgado et al. 1999). The recent epidemic of SARS is attributed to livestock cultivation in high-density population centers in China.

The Food and Agriculture Organization (FAO) predicts that "structural change in food consumption patterns in the developing countries towards more livestock products will continue with significant increases in per capita consumption of meat in all regions except South Asia and Sub-Saharan Africa. However, their per capita consumption of such products will still be below those of the high-income countries in 2010" (FAO 1995). The two exceptions are South Asia, mainly because of cultural restrictions on meat consumption; and Sub-Saharan Africa, due to economic stagnation and the lack of demand growth. In general, consumers favor milk and meat over other food products and the income elasticity of demand is greater than unity (Upton 1997).

In terms of environmental impacts, the growth of livestock production is less important relative to the intensity of animals per hectare of land. Over the past 35 years, the population of cattle, pigs, and goats in the world has increased by 30%, 80%, and 96%, respectively. In the same period, chicken populations have expanded by 250% (see Table 3). Upton (1997) points out that although the majority of livestock is housed in the developing world, most meat, milk, and eggs are consumed in the developed world. Conversely, per capita (animal) production of beef and milk in developed countries is four to six times that of developing countries. From an environmental point of view, it is not the production but the stocking of animals per hectare and their relationship to human population densities that is especially critical.

3 Production and consumption in the Asia-Pacific region

In particular, the Asia-Pacific region is the worst affected. It will experience substantial growth in income and population, which consequently will increase the demand for animal protein (Fisher et al. 2004). Consumption patterns of livestock products are extremely diverse in Asia mainly because of significant cultural as

Table 4. Total meat and milk consumption in Asia, 1965–2000

Region	Meat (million metric tons)					Milk and products (million metric tons)				
	1965	1975	1985	1995	2000	1965	1975	1985	1995	2000
Asia	14.3	22.4	39.4	78.1	97.3	38.8	52.6	85.4	128.2	152.3
Asia developed	1.2	2.7	4.3	5.8	6.1	3.1	6.0	8.0	9.7	9.8
Asia developing	13.1	18.7	35.1	70.1	89.2	35.6	46.5	77.3	109.3	132.2
China	6.7	9.9	20.8	48.0	64.2	1.8	2.3	4.8	9.5	12.4
India	1.8	2.2	3.1	4.5	5.0	16.2	22.7	38.9	55.0	65.4
Indonesia	0.4	0.5	1.0	1.9	1.7	0.2	0.4	0.9	1.4	1.5

Source: FAOSTAT 1997, 2006

Table 5. Per capita meat and milk consumption in Asia, 1965–2000

Region	Meat (kg/year)					Milk and products (kg/year)				
	1965	1975	1985	1995	2000	1965	1975	1985	1995	2000
Asia	7.71	9.16	13.99	22.86	26.52	20.89	22.47	30.30	37.49	41.54
Asia developed	11.86	24.1	34.28	44.57	45.93	30.90	52.65	64.44	74.44	73.48
Asia developing	7.47	8.39	13.05	21.78	25.78	20.32	20.91	28.71	33.96	38.16
China	9.10	10.63	19.32	39.15	50.09	2.41	2.42	4.50	7.67	9.65
India	3.67	3.62	4.06	4.79	4.92	32.73	34.99	50.88	59.04	64.36
Indonesia	3.59	3.98	6.29	9.71	8.26	2.15	3.34	5.62	7.04	7.17

Source: FAOSTAT 1997, 2006

well as income differences across regions and countries. For example, beef is mainly consumed in Japan and Australia, while pork is the main meat consumed in East Asia, and poultry in the developed countries in the region (see Table 4). On the other hand, milk is largely consumed in the developed countries of Asia and in South Asia (see Table 5). Annual growth rates for per capita consumption of nearly all livestock products are in the range of 3%–4%. Most animal production in Asia still takes place in grazing and pastoral systems (cattle, sheep, and goats) and in mixed, rain-fed, and irrigated farming systems that integrate crop and livestock production (Steinfeld 1998). However, industrial production systems, which were almost nonexistent until recently, contribute a small but increasing share of production.

Table 5 shows the per capita meat and milk consumption in Asia during 1965–2005. During this period, India increased its consumption of milk and milk products by more than 96%. Moreover, per capita meat consumption in China rose by over 450%. Livestock demand in the region is increasing because of several factors including population, income growth, and urbanization. Asia's population is growing at about 1.7% annually with 2.1% in South Asia and only about 0.6% in the developed countries of the region. The formation of free trade zones under the Uruguay Round and economic integration within the newly industrializing economies has created opportunities for trade in livestock products. Investments have been made throughout Asia in processing facilities and

the transportation of livestock products, especially close to urban areas. This process is in no way complete, and continued increases in supply will create severe pressures on the Asian environment (Steinfeld 1998).

Steinfeld argues that the role of livestock in the continent is changing away from the asset, petty cash, and insurance functions that are being performed by emerging financial institutions in rural areas, while government subsidies are promoting mechanization at the expense of draught animal power. Similarly, the role of manure as nutrient for farming is declining due to the availability of cheap fertilizer. Traditional animal products such as wool and leather are being replaced by synthetic substitutes. Animals are being bred to maximize production of lean meat, while bones, blood and other products are recycled to produce feed. Conversion efficiencies are maximized by choosing monogastrics (such as pigs).

The FAO mapping of human and livestock populations in Asia (FAO 1995) shows that the humid regions are experiencing a rise in populations of both these species, bringing animals and humans closer together and increasing environmental and public health hazards. Livestock production is changing as the value of marginal product of labor declines in traditional systems, leading to the migration of labor to the commercial sector. This has resulted in the substitution of capital for labor as well as a structural reorganization of industry. For example, poultry production often changes from a simple farm operation to a complex vertical operation including grain production for animal feeds, feed mills, slaughterhouses and processing plants, food chain stores, and wholesale enterprises (Chantalakhana 1996).

The encroachment of cropland into traditional pasture lands is another important factor that has contributed to this shift. This results in the use of marginal lands in grazing, thereby causing declining productivity, in turn triggering a shift of resources from traditional to more efficient industrial systems of production. The developing countries of Asia often run a trade deficit in ruminant meat but a surplus in monogastric meat (Fisher et al. 2004). While the region as a whole is self-sufficient, Australia and New Zealand make up the deficit, especially in beef and milk. Other countries are expected to face large deficits in livestock products, such as Indonesia in red meat and Taiwan, which imports 95% of its concentrate feed.

Steinfeld (1998) contends that although both modern and traditional systems coexist, it is essentially a disequilibrium situation, with resources continuing to flow from the low-productivity, low-input traditional grazing system to the modern capital-intensive livestock industry. However, the traditional system may still thrive in regions with low population densities, such as in some areas of the Philippines, Indonesia, and China. This trend will be strengthened if government policies are developed to strengthen traditional institutions and increase local access to common resources. Otherwise, any intensification of this system will result in the degradation of the natural resource base. Mixed farming systems such as those prevalent in the Himalayan hills are in danger from growing populations, fragmentation of arable land, poverty, and lack of easy market access. On the other hand, substitution into the intensive model of production in peri-

urban areas is fraught with major environmental risks. This has led Singapore to completely abandon livestock production in the state (Taiganides 1992).

4. A simple model of livestock intensification

In this section, we develop a von Thünen framework to examine the intensification of livestock production and its effects on land use. We consider a simple spatial model of pollution by an agricultural firm. Consider a representative firm (such as a farm) located at some distance x from the city center. The firm engages in livestock production, the output for which at distance x is denoted by $y(x)$. The production function for livestock is denoted by $f(q)$, where $f'(q) > 0$, and $f''(q) < 0$. For the purposes of this article, q represents livestock.[1] We assume the production function to be constant returns to scale; that is, it is homogenous of degree one with respect to all other inputs, including land. Specifically, all variables are expressed per unit land area. The unit prices for output and input are given by p and w, respectively. The transportation cost of carrying a unit of output per unit distance is c. Generally, inputs also may need to be transported from the city center, but we ignore this issue here and in any case, it will not change the key points we are trying to make. Then the total transportation cost of carrying output from the firm to the city center is given by cxy. We define the rent distance function of the firm from livestock production as

$$R_L(x) = (p - cx)y(x) - wq(x)$$

Assuming a competitive industry, the agricultural firm's maximization problem with respect to the input level $q(x)$ is expressed as follows:

$$\underset{q(x)}{Maximize}(p - cx)y(x) - wq(x)$$

which gives the first-order condition

$$(p - cx)f'(q) = w$$

and the second-order condition

$$(p - cx)f''(q) < 0$$

which is satisfied given our assumption of diminishing marginal returns from production. The first-order condition shows that the optimal input level is determined at the point where the value of marginal product $(p - cx)f'(q)$ is equated to the cost of input. However, the slope of the rent distance function is given by

$$R_L'(x) = (p - cx)f'(q)q'(x) - cf(q) - wq'(x)$$

which upon substituting the necessary condition becomes

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[1] The variable q may denote an index of inputs, including the quantity of livestock, labor, and equipment.

$$R'_L(x) = -cf(q) < 0$$

That is, rents decrease with distance. Note that the rent at each location also declines with the shipping cost; that is,

$$dR'_L/dc = -xf(q) < 0$$

This model can be used to examine the effect of location on intensification of livestock production. First, note that by differentiating the necessary condition above, we get

$$q'(x) = \frac{cf'(q)}{(p-cx)f''(q)} < 0.$$

That is, input use will decrease away from the city center. Consequently, the most intensive modes of production will occur in urban and periurban areas where rents per unit land are higher because of lower transportation costs.

Now let us extend this simple framework to examine alternative uses of land, such as in forestry. Suppose that a central authority allocates land to agriculture or forestry based on the net benefits from each activity. A competitive market will lead to the same equilibrium allocation. Let the derived rent distance function for this alternative use in forestry be denoted by $R_f(x)$, assumed to be exogenously given. Then the central authority maximizes the net land rent from both production alternatives at each location x as follows:

$$\underset{q(x)}{Maximize} \int_0^X ((p-cx)y(x) - wq(x) - R_f(x))dx$$

which gives the necessary conditions

$$(p-cx)f'(q) - w \leq 0 \; (= if \quad q(x) > 0)$$

and the boundary condition at the end of the agricultural system defined by X given by

$$R_L(X) = R_f(X).$$

The first necessary condition is essentially the same as before except that it allows for a corner solution with no input use. The second condition suggests that the rents from farming at the boundary of the system X must be no less than its opportunity cost, which is the rent from forestry. In other words, if for example, $R_L(X) < R_f(X)$, then land is more profitably allocated to forestry activities and not to farming.

However, there may be multiple equilibria depending on the two rent–distance functions. Figure 1 shows one plausible case. As the distance from the city center increases, rents from livestock production may decline because of higher transportation costs, until rents from livestock and forestry are equal at X. In other words, firms engage in livestock production up to location X away from the city
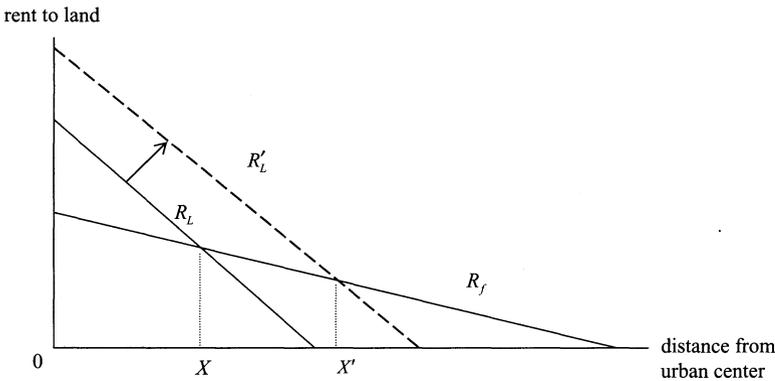
rent to land

Fig. 1. Rent–distance function for livestock and alternative land use

center. Beyond this point, there is a shift in land use from livestock production to forestry. Thus, the amount of land devoted to livestock production is the distance OX.

We can use this framework to examine the effect of population increases that could be modeled as translating into a higher demand for livestock products. In this case, an upward shift in the demand results in an increase in the output price p, which in turn shifts the rent–distance function $R_L(x)$ to the right, shown by the new function $R'_L(x)$. This leads to an expansion of the farming–forestry frontier, so that the new frontier between farming and forestry shown as X' is to the right of X. A higher price for livestock products p leads to a lower value of $q'(x)$ as seen from [substituting in the relationship for $q'(x)$] above, and a higher input use at each location, because $f''(q) < 0$. Livestock production intensifies at every location. Moreover, land that was previously under forestry or in other alternative uses, is now converted to livestock production (Fig. 1).

Next let us assume that the production of livestock leads to negative environmental externalities, for instance in pig and poultry production. For simplicity, let the opportunity cost of land be given by the rent–distance function in dairying, denoted by $R_d(x)$, which we assume does not create significant externalities relative to pig and poultry production. Let the externality damage be the cost t per unit input use q. This is the environmental cost per unit input use and does not vary across locations. For example, this may be the cost of cleaning up the waste produced per head of livestock used on the farm. The agricultural firm's maximization problem then becomes:

$$Maximize \int_{q(x)}^{X} \big((p-cx)y(x)-wq(x)-tq(x)-R^d(x)\big)dx$$

so that the necessary conditions are

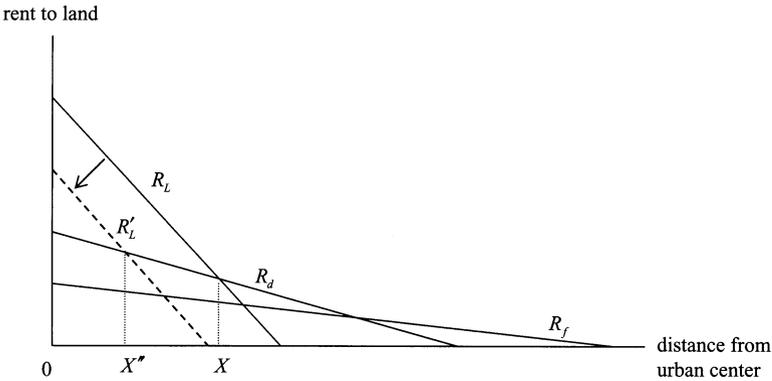$$(p-cx)f'(q)-w-t \leq 0 \, (= if \quad q(x) > 0)$$

rent to land

Fig. 2. Rent–distance function with environmental externality

and the boundary condition is

$$R_L(X) = R_d(X),$$

where $R_L(x)$ and $R_d(x)$ are the rent–distance functions from pig and poultry production (now with the negative externality) and from dairying, respectively, and X denotes the boundary of the pig and poultry production system. The first-order condition shows that the value of marginal product from livestock production is now equated to the cost of input plus the cost of the environmental externality. Because the social cost of livestock farming increases with the externality, land rents decline and thus, the negative environmental externality from pig and poultry production leads to a new switch point from pig to dairy production shown by X', which is closer to the city center (Fig. 2). The function R_f denotes rents from land use in forestry. In a market equilibrium where the externality is not regulated, we will have too much land under livestock production with a negative externality and too little in alternative uses. Moreover, there will be higher than optimal input use at each location and too much pig and poultry production. Note that if the rents from forestry are lower than in these alternative land uses, no land will be under forestry, as can be seen by shifting the forestry rent–distance function down in Fig. 2. Although he does not employ a formal model, Upton (1997) uses this framework to disaggregate livestock production into (1) pigs and poultry, (2) dairying, and (3) ruminant meat production using grazing as the primary feed source (see Fig. 2). He concludes that rents per acre are highest for pigs and poultry. Dairying yields lower rents per hectare because of relatively high transport costs. The yield from range lands are the lowest of the three. Productivity may change over time, because of a shift in the value of model parameters. For example, a relatively high rate of productivity growth in industrial livestock systems relative to ruminant production will increase intensity as well as the area under pig and poultry production. This is the same effect as an upward shift in the function $f(q)$ in the model described earlier.

5 Externalities from livestock production

We now discuss the externalities from livestock production in light of the optimization framework presented above. Within a "traditional" mixed crop–livestock system, livestock production can actually be beneficial to the environment. Livestock recycle nutrients on the farm, produce economic value on lands that are otherwise not suitable for crop production, as well as provide energy (dung and methane conversion) and capital for successful farm operations (Delgado et al. 1999). Low intensity livestock systems that primarily rely on grazing are especially sensitive to stocking rates, settlement of human populations, crop encroachment on pastureland, and deforestation.

However, growth in the demand for animal products (meat, milk, and leather) has precipitated a transition away from traditional production to a more intensified agricultural system. This industrialized livestock production has a number of unforeseen consequences both in the environmental and public health areas as described below.

5.1 Environmental externalities

In general, there has been a shift from traditional feed resources such as grazing land and crop by-products to high-energy feeds such as cereals and oilcakes, as well as to producing monogastric animals such as poultry and pigs that have a higher feed conversion ratio. Cereal crops themselves cause significant environmental externalities because of their high pesticide, fertilizer, and water requirements.

The intensification of livestock production, however, has had serious environmental consequences from overgrazing, deforestation, nutrient depletion, and manure disposal. Not all of these externality costs are reflected through the price mechanism for meat and milk products; therefore, livestock intensification may not only be at a higher level than when the externalities are regulated but as we have seen in the analysis of the model, more lands may be under livestock production than is socially optimal. Thus, regulation of the externality through taxation, for example, may not only help reduce input use, but reduce the amount of land allocated to livestock production, as the model predicts.

Moreover, there may be some asymmetry in the apportioning of benefits and costs of pollution. The damages may be borne primarily by urban and periurban populations, while the benefits accrue to the industry in particular. In general, the degree of environmental regulation seems to correlate with the level of economic development of the country in question. Low-income countries are often ill equipped to deal with the complex policy instruments necessary for the control of livestock pollution. These countries focus primarily on more basic issues of food production and security rather than environmental conservation (Steinfeld et al. 1997).

The process of intensification as a supply response to the growing demand for livestock products has led to a major imbalance between the prevailing animal

concentration and the waste absorption capacity of land (Delgado et al. 1999). Many regions in the developing world as well as in the developed world show an excess of nutrients in the soil within the range of 200–1000 kg of nitrogen per year (Steinfeld et al. 1997). Nutrients seep into the groundwater or in runoff, polluting the water and affecting marine and wetland ecosystems. Livestock populations also emit gases that are harmful to the earth's atmosphere, including ammonia, carbon dioxide, methane, and nitrous oxide—the last three play an important part in the buildup of greenhouse gases and global warming.

Livestock and manure contribute about 16% of the earth's annual production of 550 million tons of methane. These gases are produced when livestock ingest large amounts of grasses and other fibrous feeds. Emissions per unit feed are higher when feed quality is low, as in many developing countries. Table 6 shows methane emissions by species and system. Dairy cows and other cattle contribute about 54 million tons out of a total of 72 million tons of methane emissions produced by livestock. Emission figures by region suggest that Asia, Central and South America, and OECD countries account for more than 50% of the total emissions. Mixed production systems in the temperate regions are the largest contributors. Furthermore, animal manure contributes nitrous oxide, the most potent of all greenhouse gases—almost 320 times stronger than carbon dioxide (Bouwman et al. 1992).

A major environmental issue is the introduction of modern livestock feeds that have trace elements that increase feed conversion efficiencies. The digestive

Table 6. Methane emissions by species and system (million tons)

	Dairy cows	Other cattle	Buffalo	Sheep and goats	Total
Emissions by region					
Sub-Saharan Africa	0.9	5.5	0	1.4	7.8
Asia	1.6	8.2	7.6	2.6	19.9
Central and South America	2.3	13.1	0.1	0.7	16.1
West Asia and North Africa	0.5	0.6	0.2	1.2	2.6
OECD	4.6	9.5	0	2.7	16.8
Eastern Europe and CIS	3.5	2.8	0	1.3	7.6
Other developed countries	0.1	0.7	0	0.3	1.1
Emissions by production system					
Grazing temperate	0.7	2.2	0	1.1	3.9
Grazing humid	0.5	7.9	0	0.9	9.3
Grazing arid	0.6	4.6	0	1.7	6.8
Mixed temperate	6.8	7.9	0	1.8	16.6
Mixed humid	1.6	6.5	1.2	0.7	9.9
Mixed arid	1.1	4	2.2	1.4	8.8
Irrigated temperate	1	1	0.4	0.6	2.9
Irrigated humid	0.4	2.1	1.7	0.5	4.7
Irrigated arid	0.8	2.6	2.4	1.4	7.3
Industrial ruminants	0	1.6	0	0.1	1.6
Total emissions	13.5	40.4	7.9	10.1	71.9

Source: US EPA (1995)
CIS, Commonwealth of Independent States

process concentrates the trace elements such as copper, zinc, and cadmium, which are then found in significantly higher concentrations in animal manure and slurry. These products from livestock operation in turn are used as fertilizers and often the metal concentrations are transferred to crops. These elements together with antibiotics and growth hormones are often found in the final meat products sold to consumers.

Much of the intensive livestock production in the urban areas of developing countries occurs in the informal sector (Delgado et al. 1999). Competition arises between the informal sector and the newly emerging multinational and other companies. The latter tend to be subject to some degree of regulatory control by governments. Thus, any attempt to regulate these informal sector industries is often viewed as a political attempt at taking jobs away from the poor. In any case, governments of developing countries are often more concerned with making sure that there is enough supply of livestock products and that food prices are low in urban areas, rather than designing and implementing regulatory measures that may have the opposite effect.

The increase in demand for livestock products examined in the above model is also due to the new market for leather goods, which contributes to the increase in the total stock of animal and animal processing in developing countries. In recent years, the number of animals slaughtered increased sharply in developing countries, particularly in Asia (see Table 7). Global leather production has gone through a major structural transformation; there has been a shift to developing countries since the late 1960s. Table 8 shows leather production by type and region during 1968–2001. Leather production in developed countries decreased by 51%, while that in developing countries increased by 137%. Tanning industries that produce light leather have rapidly expanded in developing countries, especially in Asia and the Pacific (FAO 1992). By the end of 2001, 59% of light leather from bovine animals and 72% of light leather from sheep and goats came from developing countries. This trend is reflective of the rapid expansion of tanning industries in developing countries, especially Asia.

Three types of animal-product-processing industries, namely, slaughtering, tanning, and milk processing, produce the most severe wastewater problems.

Table 7. Animals slaughtered by region, 1965–2000

Region	Slaughtered animals (million head)				
	1965	1975	1985	1995	2000
World	1141	1367	1675	2084	2255
Developed countries	672	760	845	806	764
Developing countries	470	607	830	1278	1491
Asia	319	426	609	1022	1202
Latin America and the Caribbean	84	105	125	166	168
Sub-Saharan Africa	59	70	93	113	132

Source: FAOSTAT 1997, 2006. Slaughtered animals include cattle, buffalo, sheep, goats, and pigs

Table 8. Leather production by type and region, 1968–2001

	Annual average production (1000 tons)				Share of world (%)		
	1968–1971	1988–1990	1999–2001	Growth	1968–1971	1988–1990	1999–2001
Heavy leather							
World	504	424	495	(16.0)	100.0	100.0	100.0
Developing countries	132	187	313	41.6	26.2	44.2	63.2
Developed countries	372	237	182	(36.5)	73.8	55.8	36.8
Light leather from bovine animals							
World	6221	9972	11 000	60.3	100.0	100.0	100.0
Developing countries	2158	4477	6534	107.4	34.7	44.9	59.4
Developed countries	4063	5495	4465	35.2	65.3	55.1	40.6
Light leather from sheep and goats							
World	2795	3729	4502	33.4	100.0	100.0	100.0
Developing countries	44	1985	3245	135.3	30.2	53.2	72.1
Developed countries	1951	1744	1256	(10.7)	69.8	46.8	27.9

Source: FAO (1992, 2003)

Table 9. Characteristics of wastewater produced by different animal-processing industries

Processing type	Unit of analysis	Analysis			
		BOD	SS	N	P
Red meat slaughterhouses	kg per ton LWK	5.0	5.6	0.68	0.05
Red meat packinghouses	kg per ton LWK	11.0	9.6	0.84	0.33
Poultry slaughterhouses	kg per ton LWK	6.8	3.5	NA	NA
Tanneries	kg per ton raw hide	100.0	200.0	NA	NA
Dairies (consumption milk)	kg per ton milk	4.2	0.5	<0.1	0.02

Source: Verheijen et al. (1996)
LWK, live weight killed; BOD, biochemical oxygen demand; SS, suspended solids; N, nitrogen from organic sources and ammonia; P, phosphorus; NA, not available

High water use in various stages of animal processing is typically associated with high levels of pollution (Verheijen et al. 1996). Table 9 indicates the characteristics of wastewater produced by different animal-processing industries. In tanneries, the levels of biochemical oxygen demand (BOD) and suspended solids (SS) in wastewater are particularly high. Thus, a major contributor to environmental pollution is likely to be the tannery industries now relocating to many developing countries (Verheijen et al. 1996).

Industrial livestock production is a serious problem in many developing countries, especially in the perimeter of major urban centers where demand for meat, milk, and eggs is high, transport costs are relatively low, and there is often a total absence of any regulatory framework. For example, Dar es Salaam, the capital of Tanzania, is estimated to have 20 000 dairy cows within its city limits. Human population densities tend to be high in these areas, and thus the environmental and public health effects of livestock pollution are more serious than under traditional livestock systems. Government policies have often encouraged the process of intensification, for example, by providing subsidies for feed as well as energy and capital (Delgado et al. 1999). These policies implicitly increase the rents from industrial livestock production relative to less intensive systems and thus favor the former over the latter.

5.2 Public health externalities

The public health effects of the coexistence of dense populations of humans and livestock are serious and have been discussed extensively by Delgado et al. (1999). These externalities also increase the social cost of livestock production and create the same basic set of problems we have discussed in reference to environmental externalities. The spread of SARS in 2003 revealed the danger of spreading an unknown virus in a relatively short period of time via international travelers. SARS caused 916 deaths from November 2002 to August 2003 (WHO 2003a). SARS is caused by a previously unrecognized new corona virus that is known to have emerged in Guangdong Province, China, where dense

concentrations of domestic animals live in built-up urban centers (WHO 2003b). These public health externalities, if unregulated, lead to intensification and geographical spread of livestock operations that are higher than what is socially optimal, as predicted by our model.

Often the growing demand for animal products cannot be met by local supply, thus necessitating trade between regions. International trade in animals and animal products increase the risk of disease transmittal between countries. As livestock production intensifies, the use of sophisticated practices such as veterinary medicine also increases. Unfortunately, the widespread use of antibiotics leads to new and resistant strains of *Salmonella* (S. Typhi, S. ParatyphiA, S. Typhimurium, S. Enteritidis), *E. coli*, and *Listeria* (listeria monocytogenes) (Delgado et al. 1999). The avian flu epidemic in chicken populations in Hong Kong in 1997 is one example. Mackenzie (1998) suggests that the next lethal flu may come from pig slaughterhouses in Europe. In the USA alone, 3 to 12 million infections and 3900 deaths are estimated to arise from food-borne diseases (WHO 1997). Salmonella infections, which mostly come from chicken, are estimated to exceed 50 000 annually in the USA (WHO 1997).

Intensification of the livestock industry increases the impacts of pathogenic outbreaks. The SARS epidemic highlighted the danger of human interaction with dense animal populations. Six million swine were destroyed in the Netherlands to eradicate swine fever in 1997. In March 1997, an epidemic of foot and mouth disease (FMD) in Taiwan led to the slaughter of five million pigs and affected Taiwan's export of pork to the Pacific Rim. In April 1999, an outbreak of pig virus in Malaysia called the Nipah virus killed more than 100 people and caused the extermination of more than 1 million pigs. More recently, in 2001, Britain suffered an outbreak of FMD that led to the culling of more than 2 million animals (Herbert 2001). Insufficient temperatures used in converting animal tissue into feed are reported to be the cause for bovine spongiform encephalopathy (BSE), widely known as mad cow disease (WHO 1997). Relative to ruminant meat production, the slaughterhouse environment is especially conducive to rapid proliferation of microbial and other contaminants. In the future, with the steady switching of production to stall-fed environments, disease outbreaks in developing countries with no or little regulation is expected to be significantly higher than what has been observed in the more strictly controlled developed country farms. Thus, intensification in livestock production and processing is expected to exacerbate the spread of disease.

Both the environmental and public health externalities are important problems that need to be regulated. However, it is possible that from a management point of view, the latter are exacerbated in the presence of other factors such as high population densities. For example, with a higher population, one may observe a larger impact from higher pesticide or fertilizer use on the farm. However, the damage from an outbreak of avian flu may be significantly higher when population densities are high. So although there are damages along both these dimensions, the public health impacts may increase in a nonlinear fashion when other supporting factors are present.

6 The regulatory framework in the developed countries: the US example

As our model shows (see Fig. 2), even if the rents from pig and poultry production are higher than from dairying and rangeland beef, if the environmental externalities such as pollution and human infection from the former are relatively high, the social benefits from pig and poultry may be lower. In that case, even if it is privately profitable to allocate land for pig and poultry production, the social optimum may suggest otherwise. That is, the rent–distance function for pig and poultry may shift down by a larger magnitude than for the other two alternative production systems. This scenario may be especially relevant for developed countries, where the valuation of environmental amenities is likely to be higher.

Public health externalities in developed economies associated with intensive livestock production are typified by the recent (fall 2006) *E. coli* outbreak in the USA associated with fresh bagged spinach. There were a reported 199 individuals infected from contaminated spinach. Of these, more than half were hospitalized, and three died. The outbreak was linked to contaminated streams and livestock in the area of production (Brackett 2006; King 2006).

The intensification of livestock operations in developed countries has occurred only very recently. For example, in 1980, only 2% of beef feedlots in the Great Plains region of the United States contained more than 1000 head of cattle each. However, by 1991, 32% of the feedlots confined more than 1000 head each. The hog population is still expanding in states such as North Carolina and Oklahoma, where huge processing companies establish contractual relationships with local hog producers (Frarey and Pratt 1995). The dairy and poultry industries also show similar trends toward larger operations located close together as in Erath County in Texas and Washington and Benton Counties in Arkansas.

Environment regulators in the USA quickly recognized the problem of pollution from livestock waste. An assessment under the Water Pollution Control Act published in 1993 revealed that a third of all agriculture-related water pollution came from livestock waste. Groundwater contamination from livestock waste has been reported in several states including California, Delaware, Pennsylvania, and Arkansas. Waste from centralized livestock production facilities is substantial. For example, waste generated by broilers and other species in the Washington and Benton Counties in Arkansas is equivalent to that generated by a city of 8 million people (Holleman 1992).

Two hundred and seventy-five dairies in Tulare County in California produce over 3.4 million tons of wet manure annually. Nitrogen, phosphorus, and fecal bacteria are most commonly found in manure. Unlike human waste, which is treated prior to disposal, livestock waste is often collected in lagoons and directly applied to land (Frarey and Pratt 1995). Because of the heavy nutrient loading of these wastes, operators need to manage volumes, rates, and location of these applications.

Large concentrations of phosphorus and nitrogen stimulate production of aquatic plants and disturb the ecosystem by depleting the level of oxygen in

streams. Eutrophication causes algal blooms which in turn decrease water filtration and result in increased deaths of marine animals and cause odors. Episodic pollution such as the 1993 outbreak of cryptosporidium (Cryptosporidium parvum) in Milwaukee that caused 400 000 people to suffer from diarrhea, vomiting and stomachache, and dozens of deaths was attributed to an unusually heavy spring runoff. Cattle, sheep, goats, and swine are major vectors of this parasite. A survey of cryptosporidium in 28 states revealed that 90% of the farms were infected at any given time (Pratt et al. 1997).

The United States deals with livestock runoff primarily under the Clean Water Act. The Act distinguishes between point and nonpoint sources. Discharge from animal confinements and process areas represent point sources of pollution, while application of manure solids and lagoon effluent to pasture or cropland may cause nonpoint source pollution in the presence of precipitation (Pratt et al. 1997). Any concentrated animal feeding operation (CAFO) can discharge pollutants based on possession of a permit issued by the National Pollutant Discharge Elimination System (NPDES). Effluent limitations guidelines are established based on use of best available technology (BAT). While the Environmental Protection Agency (EPA) regulates CAFOs as point sources, nonpoint sources such as precipitation-induced runoffs or leaching of pollutants through soil layers is regulated by state and coastal management plans wherever relevant. However, CAFO has been treated as low priority and in 1992 only 10% of the 10 000 designated CAFOs held an NPDES permit. There are some loopholes that allow CAFOs to avoid obtaining an NPDES permit, for instance if their lagoon can contain all wastewater absent a 25-year 24-h storm event.

Because of a low priority afforded to CAFO permitting, a significant number of water bodies are impaired by livestock waste (Pratt et al. 1997). In EPA Region VI, consisting of Texas, Oklahoma, New Mexico, Arkansas, and Louisiana, the EPA issued a general permit in 1993 that covered all CAFOs in all the states except Arkansas, which standardized the compliance process. This permit required CAFOs to develop a pollution prevention plan and retain it on site. These plans are expected to be quite elaborate and include information on construction and operation of waste containment structures, practice of best management techniques for application of solid and liquid manure to designated agricultural fields, and the capacity of crops or pasture grass to utilize the nitrogen or phosphorus. The permit allows excess disposal where application sites are isolated from groundwater sources (Pratt et al. 1997).

A survey of state regulation of livestock production facilities by Pratt et al. (1997) found that even in those 39 states where the EPA has delegated CAFO permitting authority to the state, the degree of regulation has been inconsistent. Site inspection and enforcement of discharge limits are sporadic at best. Enforcement is also made difficult because usually several application sites are used by a single farm and there is a large degree of heterogeneity even within a single watershed. For example, any single watershed may have up to a 100 dairies, each with an average of four application fields. Because the amount of manure application is usually impossible to determine ex-post, an inspector must be present

during application. Moreover, runoff from these fields occurring during a single storm event may vary substantially in nutrient concentration.

The substitution of nutrient loadings under regulation is another important issue. Nitrate regulation encourages farmers to substitute into using phosphorus. Phosphorus standards lead to a much larger land-base requirement for manure application relative to nitrates.

These issues suggest that the regulatory mechanism, even in an industrially advanced country such as the United States, and in areas that do not have the complexities of a dense urban environment, is far from perfect. It also reveals the complex nature of the problem faced by developing countries where the coexistence of high-density human and livestock populations in close geographical proximity make the task of damage assessment, calculation of public health risks, and inspection of sites so much more difficult. The problem is further complicated by the typically weak regulatory environment and low political priority for meeting environmental goals found in lower income countries.

Other developed economies such as in the EU also face severe livestock regulation issues. One common element that can be extracted from their cumulative experience is the issue of who bears the cost of pollution abatement. In the UK, farmers have resisted the notion of pollution abatement simply because in their view, they will become bankrupt from being forced to pay for manure disposal or for reduction of livestock numbers if manure disposal exceeds prescribed limits (Pratt et al. 1997). A ban on seasonal applications of slurry and sludge to grasslands in certain regions would also be costly to farmers if they have to pay for alternative disposal processes.

In the USA, the state of Texas has addressed this problem by providing cost-share assistance to farmers who adopt best management practices (Pratt et al. 1997). The US government is targeting additional resources to facilitate costly compliance. However, given heterogeneity across watersheds, not all would be equally impacted and given limited monitoring and assessment resources, some watersheds may be chosen as priority areas that can then receive specifically targeted resources for modeling, assessment, and enforcement provisions. Pratt et al. (1997) suggest the use of organizations that have traditionally worked with farmer's groups such as the Soil and Water Conservation Service as conduits in the implementation of pollution-control programs. Second, where complaints are made, it may be cost effective to elicit the producer's cooperation in addressing it before taking the next step toward costly enforcement or litigation.

A major lesson from the regulatory experience in the developed world is the need to focus on subbasins or microwatersheds. Monitoring data suggests that the percentage of land used for waste application in a drainage basin is positively correlated with the pollution loading in stormwater runoff and downstream reservoirs. Thus, focusing on microwatersheds may reveal problem areas more easily than looking at the aggregated watershed. A smaller watershed also has the advantage of lower transactions costs in organizing stakeholders in developing pollution management plans in close collaboration with regulatory authorities.

Local participation in the management process makes it easier to identify specific sources of pollution loadings that need to be sampled for contaminants.

7 Concluding remarks

The environmental issues relating to agricultural industrialization in developing countries are exceedingly complex, partly because of a rapid growth in demand for agroindustrial products that has encouraged the intensification of livestock and other animal-based production systems close to major urban centers. In this article, we present a simple analytical framework to examine this issue, and discuss the economics of livestock intensification and the associated regulatory challenges. The analysis shows that a lack of regulation of the environmental and health externalities is likely to lead to intensification as well as a higher than optimal allocation of land to livestock production.

Our review shows that even in developed countries, the regulatory system is far from perfect. On the other hand, in developing countries, there is very little systematic information on the nature and extent of pollution from agroindustrial wastes. However, preliminary evidence such as the recent outbreaks of SARS and avian influenza suggests that the problem is serious, given the coexistence of high-density human and livestock populations in close proximity to each other. From a policy perspective, regulatory agencies in developing countries face a difficult challenge. Precise knowledge of how the pollution generated from intense agroindustrial systems located close to major population centers interacts with human activity and health is not yet available. Moreover, given the higher probability of episodic outbreaks, response times may need to be much shorter in a developing country. One way to mitigate the environmental impact would be to adopt tax and subsidy policies that shift agroindustrial production to regions with lower population densities.

While market mechanisms or the "polluter pays" principle are appropriate from a theoretical point of view, the task of regulation is complex, and the political will to do so is inadequate. Most developing countries are preoccupied with increasing milk and meat production and keeping their prices within reach of the politically active urban poor. Economic liberalization of the livestock sector and opening up to international agribusiness corporations may have a beneficial effect on the environment, because these large enterprises may be easier to regulate than the thousands of informal sector industries located near urban centers. However, with the onset of a free trade regime and the imposition of environmental standards on imported products, most developing countries may have to install inspection and enforcement mechanisms that ensure product safety and quality. However, free trade may in turn encourage the movement of polluting agricultural industries from developed to developing countries, which will exacerbate the environmental and regulatory challenges.

More systematic research is necessary to model the agroindustrial system by explicitly considering population size, which drives demand for final products as well as creates a higher likelihood of environmental damage. While agroindustrial

activity needs to be located close to urban centers to reduce transport costs, they need to be located away from them to reduce externality costs. The Ricardian framework presented here can be used to model trade in agroindustrial products in situations where consumers in developed and developing countries have different valuations of environmental externalities (Copeland and Taylor 1995).

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