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# THE OPTIMUM BIAS OF TECHNOLOGICAL INNOVATIONS IN THE CONTEXT OF TRANSACTIONS COSTS AND LOBBYING*

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## Abstract

The neoclassical theory of induced technological innovations, pioneered by Hayami and Ruttan, has shown that changes in relative factor prices help explain the bias of technological change. We show in this paper that, when transactions costs on labor and land exist, structural and political factors are additional important determinants of the bias of technology. The size of the research budget, average farm size, and inequality in the distribution of farm sizes are econometrically shown to all add to relative prices in explaining the bias of technology. A larger research budget is, in particular, observed to lead to a bias more congruent with democratic rules of public budget allocation.

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* This paper summarizes: Alain de Janvry, Elisabeth Sadoulet and Marcel Fafchamps, Agrarian Structure, Technological Innovations, and the State", forthcoming in P. Bardhan ( The Economic Theory of Agrarian Institutions, Oxford University Press.

# THE OPTIMUM BIAS OF TECHNOLOGICAL INNOVATIONS IN THE CONTEXT OF TRANSACTIONS COSTS AND LOBBYING

The neoclassical theory of induced technological innovations (NCTITI) has proved to be effective in providing a first approximation to the explanation of the bias of technological change. It has, for example, enabled Hayami and Ruttan to explain why the United States and Japan have followed such sharply contrasted technological paths.

As in other neoclassical formulations, the NCTITI postulates the existence of perfect markets for all factors and products and, hence, the absence of market failures and transactions costs. Efficiency in the allocation of resources is unaffected by the personal distribution of assets. Changes in relative factor scarcities are uniquely translated in changes in relative factor prices. Technological innovations are guided by the quest for saving on the factor that becomes relatively more expensive. When technological innovations are public goods, the state responds to farmers' demands for cost-saving technological innovations by allocating research budgets toward increasing the productivity of this particular factor. Because markets are perfect, all farmers have the same demand for a specific bias of technological change, and the state responds to this unique demand. There, consequently, exist no conflicts among farmers in their demands for technological innovations, and the state is able to respond indiscriminatively to these demands.

Recent studies by Stiglitz and others have amply demonstrated how the introduction of transactions costs into rational choice models implies that the personal distribution of assets affects the optimum allocation of resources. Transactions costs have their origin in the possibility of opportunistic behavior in transactions among individuals. They include such costs as the gathering of information and the negotiation, supervision, and enforcement of contracts. If, for example, hired labor tends to shirk, supervision costs must be incurred. The price of a unit of effective labor will, consequently, rise as the number of hired workers relative to family labor increases, i.e., in general with farm size. A transactions cost on land, originating in a fixed cost on land sales or rentals, implies that the effective price of land declines with farm size.

We show, in this paper, how the introduction of transactions costs on labor and land implies that the optimum technological bias is no longer unique but varies systematically across farm sizes. Different classes of farmers and an autonomous state that maximizes sectoral value added will, consequently, all have different demands for an optimum technological bias. As opposed to state neutrality in the NCTITI, the mechanisms of decision-making by the state become key determinants of the bias of technological change. The relative effectiveness of lobbies of small and large farmers and the degree of relative autonomy of the state are the bargaining mechanisms through which the bias of technological change is established. In addition to prices, as evidenced by NCTITI, structural and political factors are thus also fundamental determinants of the bias of technological change.

## The Basic Model

Agricultural technology can usefully be contrasted between land-saving and labor-saving innovations embodied in capital. To reflect this structure of technology, we use a two-level CES production function as follows:

$$Q = \left[\gamma X_A^{-\rho} + (1 - \gamma) X_L^{-\rho}\right]^{-1/\rho}$$

$$X_A = \left[\alpha A^{-\rho_A} + (1 - \alpha) (E_F F)^{-\rho_A}\right]^{-1/\rho_A}$$

$$X_L = \left[\beta L^{-\rho_L} + (1 - \beta)(E_M M)^{-\rho_L}\right]^{-1/\rho_L}$$

where $Q$ = agricultural output; $X_A(\cdot)$ = "land" input index; $X_L(\cdot)$ = "labor" input index; $A$ = land; $L$ = labor; $F$ = landsaving capital (fertilizer); and $M$ = labor-saving capital (machinery).

$E_F = E(\lambda_F\, \theta\, B)$, $E_M = E[\lambda_M(1 - \theta)\, B]$ efficiency parameters where

$B$ = research budget; $\lambda_i$ = productivity parameter, $i = F, M$; and $\theta$ = allocation of budget $B$ between $E_F$ and $E_M$. $\sigma$ = elasticity of substitution between $X_A$ and $X_L$; $\sigma_A$ = elasticity of substitution between $A$ and $E_F F$; and $\sigma_L$ = elasticity of substitution between $L$ and $E_M M$.

Based on estimations of Kaneda and others, $\sigma_A$ and $\sigma_L$ are observed to be larger than $\sigma$ and all elasticities are less than one. With transactions costs in access to labor and land, the farm-level prices of these inputs vary as follows:

$$w = w(L),\ w' > 0,\ w'' < 0$$
$$r = r(A),\ r' < 0,\ r'' > 0$$

while the prices of output (p), fertilizer (f), and machinery (m), are constant.

The farm operator maximizes profit under a credit constraint, $K(\bar{A})$, determined by the size of ownership unit $\bar{A}$. Credit availability constrains total expenditure on inputs, including the rental of land. With constant returns to scale, the credit constraint determines the level of output. The farmer's problem is thus:

$$\text{Max}_{A,L,F,M}\ p\, Q(A, L, F, M; E_F, E_M) - (rA + wL + fF + mM)$$
$$\text{subject to } rA + wL + fF + mM \leq K(\bar{A})$$
$$\text{and } w = w(L),\ r = r(A).$$

The optimum levels of factor use are

$$A, L, F, M = f(p, f, m, \overline{A}, E_i, i = F, M).$$

## Optimal Technological Bias by Farm Size

The farm-level model introduced previously is used to define the demand for technological change that would emerge from a homogeneous group of farms. Keeping exogenous the decision on the size of the research budget B, there is an optimal allocation $\tilde{\theta}$ of this budget between research on landsaving and on laborsaving technological changes which maximizes farm profit. It is determined by including $\theta$ as a decision variable of the farm operator in the maximization problem. Since land and labor costs (and, consequently, factor use), depend on the size of ownership unit $\overline{A}$, $\tilde{\theta}$ will also be found to vary with $\overline{A}$. In the general case, the solution for $\theta$ cannot be separated from the solution for the levels of factor use as they are jointly determined. Taking land and labor prices as explicit functions of $\overline{A}$, rather than as functions of the levels of factor use L and A, greatly simplifies the exposition of the problem since it allows decisions on factor use and on optimal technological change to be taken sequentially. The analysis which follows is based on this simplified model. In that case, the optimal levels of factor use and the corresponding unit cost function (c) associated with the two-level CES production function can be explicitly written as functions of the exogenous factor prices (m and f), landownership ($\overline{A}$), and the efficiency parameters ($E_i$):

$$c = c[r(\overline{A}), w(\overline{A}), f, m, E_i].$$

Total production and profit are direct functions of the unit cost:

$$Q = K/c,$$

$$\text{profits} = (\frac{p}{c} - 1)\, K.$$

$\tilde{\theta}$ derives from minimizing the cost c,

$$\min_{\theta} c[r(\bar{A}), w(\bar{A}), f, m, E_i(\theta, B), \quad i = F,L].$$

The solution to this optimization problem shows that the optimum technological bias is a function of relative factor prices as follows (see de Janvry, Sadoulet, and Fafchamps):

$$\tilde{\theta} = \theta(+f/r, -m/w, ++r/w, B),$$

where ++ indicates that the impact of an increasing r/w dominates that of a decreasing f/r if coming from a change in r only. The demand for technological change originating in large farms which face higher transactions costs on labor and lower transactions costs on land will be biased toward improvement of mechanization which can substitute for labor. By contrast, the demand by small farmers will be biased toward land-saving technological change. Rising prices of machinery reinforce the technological bias toward large farmers' demands, and rising prices of fertilizer reinforce it toward small farmers' demands.

The optimum factor ratios can also be derived as follows:

$$F/A = f(-f/r, -\tilde{\theta}, -B),$$

$$M/L = f(-m/w, +\tilde{\theta}, -B),$$

$$A/L = f(-r/w, +f/r, -m/w, -\tilde{\theta}, B),$$

Identification of the role of induced technological change on factor ratios derives from these expressions and the determinants of $\tilde{\theta}$:

(i) While direct substitution between fertilizer and land responds only to the relative price of these two inputs, technological change introduces an increase in relative fertilizer use when the price of machinery or the level of wages increase since less research is then devoted to increase fertilizer efficiency.

(ii) In the land-labor ratio, direct substitution and the impact of technological change counteract each other. From simple substitutability, an increase in the fertilizer price generates direct substitution of land for fertilizer and thus a higher land use per worker. Technological change response, by contrast, increases research in fertilizer efficiency leading to lower use of both factors, land and fertilizer, and of the land aggregate.

## The State, Lobbying, and Technological Change

Differences in relative factor use are brought about if relative factor costs vary from farm to farm due to transactions costs. In this case, the size of operation determined by the credit constraint will also affect the relative factor costs and, therefore, the research budget allocation preferred by individual farmers. Global output response to various levels of $\theta$ will now be the aggregation over all farms of differentiated impacts. In that sense, the way access to credit is distributed across farms will matter for choice by the state of an optimal $\theta$.

While each farm's demand for a specific bias of technological change is dictated by its own profit motive, the state, which provides technological change as a public good, has its own objective in the choice of bias. Minimizing food cost through a maximum sectoral output, insuring a minimum level of profit for small farmers, and underwriting the technological demands of the large farmers are alternative possible objectives for the state. To each corresponds a different optimal allocation $\tilde{\theta}$ of the research budget.

This model of induced technological innovations with transactions costs shows that, across regions or countries, technological change will be sensibly different from what would have been expected on the basis of market factor prices alone with a greater bias toward mechanical innovations where average farm size is larger. It also indicates the need for a change in the orientation of research if any tranformation of the pattern of landownership is happening or envisaged.

While the effect of average farm size on the technological bias can be derived analytically, the effect of inequality in the distribution of farm sizes ($d\bar{A}$) requires numerical simulation (de Janvry, Sadoulet, and Fafchamps). The results show that, keeping the average farm size constant, an increase in inequality reflected by a higher Gini coefficient leads to a $\tilde{\theta}$ that is smaller than the one computed on the basis of the average farm--that is for Gini = 0.

In other words, the results tell us that trying to estimate the optimum research budget allocation on the basis of the average farm size without paying attention to land distribution leads to a bias. This bias always goes in the same direction: the true $\tilde{\theta}$ is geared toward a more laborsaving or less landsaving technology, that is, closer to the interests of large farmers. In fact, the bias can never be in favor of small farmers. This means that inequality in assets distribution combined with failures in factor markets can account for at least part of the unexplained bias in favor of mechanization observed by Hayami and Ruttan. This calls for adding asset distribution as an explanatory variable when testing for induced technological change.

The farm model has shown that, with transactions costs, different groups of farmers have diverging interests concerning technological change. They will likely, therefore, try to affect the research effort in favor of their own optimal technological bias.

The state maximizes its utility which is a weighted average of its own objective goal of sectoral output maximization and the utility derived from making concessions to the lobbies of the different classes of farmers. This is equivalent to

$$\underset{\theta}{\mathrm{Max}} \int_{\overline{A}} \frac{1}{c(\theta, \overline{A})} [aK(\overline{A})\ f(\overline{A}) + bg(\overline{A})]d\overline{A}.$$

In this model, the structure of the negotiating process and the efficiency of lobbying are completely summarized by the bargaining intensity function $g(\overline{A})$ and by the weights a and b in the state's objective function.

A negotiating structure in which the power of a class of farmers is proportional to the size of their operational units or credit is characterized by

$$g(\overline{A}) = K(\overline{A})\ f(\overline{A}).$$

The lobbying model then reduces to the state optimal policy of maximizing sectoral output.

A more "democratic" decision process which gives equal power to all farmers regardless of their farm sizes is represented by

$$g(\overline{A}) = f(\overline{A}).$$

Relative to the state's optimum for sectoral output maximization, the outcome will clearly be a bias toward the demand of small farmers for technological change.

By contrast, if lobbying power is determined by the cohesion of a group and its ability to control free riding, power will be inversely related to the number of farmers in the group. In this case,

$$g(\bar{A}) = K(\bar{A}) \cdot f(\bar{A})/f(\bar{A}) = K(\bar{A}).$$

This lobbying model will induce a strong bias in the state's decision toward the requests of the large farmers.

Using numerical analysis, we can simulate the impact that various specifications of the bargaining process have on the optimum $\theta$. Using as a functional form

$$g(\bar{A}) = K^{\alpha}(\bar{A})\ f(\bar{A})$$

with $\sigma = .2$, $\sigma_L = \sigma_A = .7$, Gini of land distribution = 0.5, for the bargaining function and leaving aside the state's own objective ($a = 0$, $b = 1$), we obtain:

| $\alpha$ | $\tilde{\theta}$ | Type of bargaining |
|---|---|---|
| 0 | .63 | Democracy $g(\bar{A}) = f(\bar{A})$ |
| 0.5 | .52 | |
| 1 | .44 | State optimum |
| 1.5 | .38 | |
| 2 | .33 | |
| $\alpha = 1$ and $f(\bar{A}) = 1$ | .27 | Lobbying $g(\bar{A}) = K(\bar{A})$ |

While the state's optimum biases technology away from $\tilde{\theta} = .5$ toward the technological interests of the large farmers ($\tilde{\theta} = .44$), a democratic bargaining structure can lead to optimal research budget allocations that are favorable to small farmers ($\tilde{\theta} = .63$). By contrast, collective action when the effectiveness of lobbies is inversely proportional to the size of class membership will further distort technological biases toward the interests of the large farmers ($\tilde{\theta} = .27$).

We thus conclude that, once transactions costs are taken into account to make technological demands farm-class specific, the mechanisms of decision making at the level of the state become important determinants of the bias of technological change. The efficacy of collective action and the degree of autonomy of the state are thus essential components of a theory of induced technological innovations.

## Empirical Test: Prices vs. Structure

To estimate the relationship between factor ratios, relative factor prices, and structural variables (average farm size, inequality in the distribution of farm sizes, and size of the research budget), we use international data for 18 more- and less-developed countries in 1970.

The results obtained in table 1 are strikingly consistent with theory, both in the price and structural determinants of differences in factor ratios across countries. They show that structural variables are indeed important in explaining factor biases in induced technological innovations. In particular, larger farms and/or more inequality in the distribution of farm sizes decrease the bias toward landsaving technological change (F/A and F/M) while enhancing the bias toward laborsaving technological change (M/L) and the land/labor ratio. The direction of the impact of the size of the research budget on the bias of induced innovations could not be predicted by theory.

A surprising result is that the size of the research budget per acre of arable land tends to increase the technological bias toward landsaving technological change and away from laborsaving technological change. This has three possible explanations. One is that, as the simulation results reported

Table 1. Determinants of Factor Ratios: International Comparison

| | | $\log \frac{f}{r}$ | $\log \frac{m}{w}$ | $\log \frac{r}{w}$ | $\overline{A}$ | $d\overline{A}$ | $\frac{B}{A}$ | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| log F/A | Farmland | -2.84 | .59 | -.99 | a | -.06 | 140 | .79 |
| | | (2.93)[b] | (.62) | (1.02) | | (1.97) | (2.48) | |
| | Arable land | -1.35 | -.38 | -.39 | -.02 | | 69 | .89 |
| | | (2.36) | (.67) | (.67) | (1.94) | | (2.26) | |
| log M/L | Farmland | -1.11 | -1.13 | -.57 | | | | .88 |
| | | (1.24) | (1.29) | (.66) | | | | |
| | Arable land | -1.10 | -1.12 | -.60 | | | | .89 |
| | | (1.31) | (1.34) | (.73) | | | | |
| log A/L | Farmland | .41 | -.32 | -.23 | .02 | | -80 | .92 |
| | | (.87) | (.74) | (.50) | (5.49) | | (-2.55) | |
| | Arable land | -.21 | -.10 | -.28 | .04 | | -35 | .91 |
| | | (.63) | (.32) | (.82) | (5.88) | | (2.00) | |
| log F/M | Farmland | -.78 | 1.47 | -.97 | | -.05 | | .71 |
| | | (1.53) | (2.71) | (1.87) | | (2.33) | | |
| | Arable land | -.79 | 1.44 | -.94 | | -.05 | | .71 |
| | | (1.59) | (2.75) | (1.87) | | (2.33) | | |

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[a] Blanks indicate that the coefficient of the corresponding structural variable ($\overline{A}$, $d\overline{A}$, B/A) is not significantly different from zero at a 95 percent confidence level.

[b] Figures in parentheses are t-ratios.

above have shown, allocation of the research budget is biased toward laborsaving technological change ($\tilde{\theta} < 0.5$). Both the state's optimum choice and successful lobbying by large farmers have, indeed, shown to be biased toward laborsaving. A rising research budget may, however, relax this bias as it allows to accommodate the demands of all farmers without exclusion. Another explanation is that there exists an innate bias in research toward laborsaving technological change which also implies a laborsaving bias that only decreases with rising research budgets. Finally, it may well be that research on mechanical innovations is principally funded by the private sector, since it is easily patentable, while research on biological innovations, which is more of a public good, is funded by the public sector. Since the research budget used here is for public sector research, the observed association between budget size and land-saving bias is not surprising. In any case, the results unequivocably show that larger research budgets lead to technological biases closer to those corresponding to more democratic (pro small farms) decision mechanisms in the farm sector.

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