ESSAYS ON INEQUALITY, PRODUCTIVITY, FOREIGN OWNERSHIP, AND STANDARD OF LIVING: THE CASE OF MEXICO

by

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Abstract

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Julio Huato

Adviser: Professor Zadia Feliciano

This dissertation is a compilation of three discrete essays. The first two, empirical and with Mexico's economy as their object of study, estimate respectively (1) the effect of foreign ownership on total factor productivity in Mexico's manufacturing sector in the 1990s and (2) the effect of maquiladora manufacturing on various non-income measures of local standard of living between 1980 and 2000. The third essay is theoretical; it sets up a dynamic game model of an economy and determines its Markovian Nash equilibrium to examine the relationship between inequality and welfare.

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This dissertation is dedicated to my beautiful, supportive, and incredibly patient wife, Mary Beth, and to my beloved children Alejandra, Aleida, and Erik Julio. With all my love.

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Chapter 1
Introduction

This dissertation compiles three discrete essays, one per chapter. The first two essays are empirical and concentrate on two different aspects of the performance of the Mexican economy in recent decades. The third essay is theoretical, and its focus is on the relationship between inequality and economic performance in an economy with a fundamental conflict of interests between its agents. A more detailed description of each essay follows.

The first essay is titled "Foreign Ownership and Total Factor Productivity in Mexico's Manufacturing 1988-1998." It uses Mexico's 1989, 1994, and 1999 manufacturing census data to estimate augmented frontier Cobb-Douglas production functions that embed foreign ownership effects. The study finds that, although by itself foreign ownership co-varies positively and strongly with total factor productivity, when interacted with capital use, plant size, labor quality, industry concentration, industry group, and time, the main foreign ownership effect is reinforced manifold.

This study covers a decade of momentous events and sweeping changes in Mexico's economic structure and policies. Unlike other works limited to establishing the overall effects of foreign investment or trade exposure on productivity, this study emphasizes specific main- and interaction foreign-ownership effects on productivity and thus reveals greater factual detail of potential use in theory and policy design.

The second essay, "Maquiladoras and Standard of Living in Mexico Before and After NAFTA," estimates the impact across states of for-export, mostly foreign-owned manufacturing plants (commonly known as 'maquiladoras') on various non-income measures of standard of living in Mexico, namely literacy rate, school enrollment rates, housing characteristics, life expectancy, infant mortality, and an overall index of human development.

The main data set used for this essay is from the population and housing censuses of 1980, 1990, and 2000. The study controls for the effect of nonmaquiladora economic activity and prior growth. To remove the endogeneity, maquiladora activity is instrumented with a measure of road transportation time to the nearest major border city in the United States. The results of the Hausman specification tests are reported. The resulting IV-TS-OLS and GLS regressions, pooled, with (state and time) fixed effects, and with interactions, are estimated. The study finds that, overall, maquiladora activity has no robust effect on the measures of standard of living analyzed.

The third and final essay, "Inequality and Growth: A Two-Player Dynamic Game with Production and Appropriation," models a two-agent economy with production and appropriation as a noncooperative dynamic game, and determines its closed-form Markovian Nash equilibrium. The analysis highlights the parametric conditions that tip the economy from a nonaggressive or "cooperative" equilibrium to outright distributional conflict.

The model includes parameters that capture the role of appropriation technology and destructiveness. The full dynamic implications of the game are yet to be explored, but the model offers a promising general framework for thinking about different technological and economic conditions as more or less conducive to cooperation or distributional conflict.

The connection between the former two, empirical essays – dealing with concrete developments in the Mexican economy – and the latter, theoretical essay – occupied with an abstract game of economic strategy – may not be apparent, but it exists nonetheless. I was born and raised in Mexico, a country with a prolonged history of social inequality, economic turmoil, and political conflict that can be traced back at least to colonial times. With such a background, it has not been difficult for me to grow increasingly convinced that the fragmentation in Mexico's economic structure and (ultimately) the tragic inequality in the distribution of its human and physical wealth, disparities that returned with a vengeance after the impetus of redistributive justice of the revolution of 1910 waned, are fundamentally related to the seemingly endless series of economic catastrophes that the country has experienced in the last four decades.

Finally, a note on the way this dissertation is organized: The appendices are numbered to correspond with the chapters that refer them. Thus, for instance, Appendix 3 corresponds to chapter 3.

Chapter 2

Foreign Ownership and Total Factor Productivity in Mexico's Manufacturing 1988-1998

2.1 Introduction

This study analyzes data from Mexico's 1989, 1994, and 1999 industrial censuses to determine the extent to which the effect of foreign ownership is a distinctively influential component of total factor productivity in the manufacturing sector, and to glean more detailed information about the deeper sources of this influence.

Although a large body of empirical literature supports the view that foreign investment and, more generally, exposure to foreign markets is a driver of productivity in less developed countries, there is no universal agreement. On the positive side, the claim is that, by some selection (survival) or causal mechanism (e.g. static and/or dynamic, internal and/or external gains from trade or factor mobility), exposure to foreign markets induces higher productivity levels or growth rates.

On the negative side, the claim is that the benefits from foreign ownership, if any, are concentrated at the top or repatriated, leading to subsequent instability in the receiving country. A related claim is that the exposure to foreign markets increases economic volatility and macroeconomic risk to an extent that offsets any possible benefit.

The importance of this issue in the economics, policy debate, and political economy of international finance and economic development is difficult to exaggerate. Under different guises, many disputes in these fields hinge on whether to expand or limit – and in which particular cases – an economy's exposure to foreign markets.

The production functions are estimated using *stochastic frontier regression*. Recent studies estimating total factor productivity persuasively advocate the use of data-driven, computationally-intensive methods to estimate *frontier* or best-observed-practice — rather than *average* — production functions. Stochastic frontier (SF) regression is more flexible than ordinary least squares (OLS) regression. In this study, both the SF and OLS results are reported. As it turns out, in this case, the difference in the results from the two methods is minor.

Overall, the results of this study are consistent with the hypothesis that foreign ownership is a significantly *positive*, direct and indirect, component of total factor productivity in the manufacturing sector. Furthermore, when interactions are specified *between* foreign ownership *and* individual input use (labor and capital), plant size, a labor quality proxy, an index of industry concentration, time, location, and industry group, the main foreign-ownership effect multiplies its explanatory power compared to the case where no interactions are specified.

In particular, two interesting facts are revealed by the inclusion of foreign ownership interactions in the estimations. First, foreign ownership and the use of the capital stock by manufacturing plants in Mexico interact negatively.[1] And second, during the 1990s, the productive gap between domestically-owned and foreign-owned manufacturing plants in Mexico grew significantly.[2]

This essay is organized as follows: Section 2.2 provides a narrow review of the literature focused on placing this study in the context of previous work on the topic. Section 2.3. gives the context on Mexico's economic conditions in the 1990s. Section 2.4 discusses the methodology. This section also adds to the literature review of section 2.2. Section 2.5 describes the data used. Section 2.6 interprets

[1]The role played by the over-capitalization of foreign owned plants in securing their total factor productivity edge over domestic plants is suggestive of a monopolistic-competition type of mechanism.

[2]Although different in nature, this result resonates with Aitken and Harrison's (1999) finding that foreign investment of plants in Venezuela's manufacturing sector impacts negatively the productivity of domestically-owned plants.

the results. Section 2.7 makes concluding remarks. Appendix 2 contains all the tables referred in the essay.

2.2 Literature

In the recent case of Mexico, a number of studies on the manufacturing sector published in the last two decades claim that exposure to foreign investment and trade is associated with higher and/or faster productivity. Kokko (1994), Tybout and Westbrook (1995), Aitken, Hanson, and Harrison (1997), López-Córdova (2002), Lederman, Maloney, and Servén (2003), Paus, Reinhardt, and Robinson (2003), Álvarez and Robertson (2004) are works that, from different angles, claim that productivity in Mexico's manufacturing grew as a result of increased exposure to foreign markets.

Bergoeing et al. (2002) hold a somewhat contrarian view. Using aggregate data, they argue that total factor productivity growth resulted only from reforms that induced efficiency in factor use, as opposed to reforms that merely induced factor accumulation. In their view, Mexico's reforms in trade and tax policies were of the latter type, whereas bank reform, bankruptcy law, and the elimination of subsidies and preferential interest rates to encourage import-substitution were reforms of the former type.

In terms of the data sources used, the nearest predecessor of the current study is Blomström 1988's study. Blomström examined plant-level data from Mexico's 1970 manufacturing census and found that, after controlling for differences in capital intensity, labor quality, and concentration, foreign-owned plants were "significantly more productive than their Mexican counterparts." Due to the limitations in his data set that prevented his estimating total factor productivity, Blomström tested the relationship using gross value added per worker as a proxy for productivity.

Detailed recent studies – such as Tybout and Westbrook (1995) and López-Córdova (2002) – use plant-level data from Mexico's annual manufacturing survey to estimate, in a first step, production functions (or dual cost functions) and, thereby, a measure of total factor productivity. Then, in a second step, they test the relationship between the estimated total factor productivity (or some component thereof) and the measure(s) of exposure to foreign markets that interest(s) them.

The present study distinguishes itself from the previous works in that it uses the 1989, 1994, 1999 census data panel to estimate total factor productivity in an augmented Cobb-Douglas production function framework that embeds foreign ownership's effects, directly and through its interactions with input use, industry group (2-digit level of classification), location (state), time (census year), and a number of controls.[3]

A statistical problem in two-step studies is that the estimation of plant- or industry-level measures of total factor productivity breaks the sample into much thinner sub-samples, thus reducing the power of the estimators. This study preserves degrees of freedom by estimating the foreign ownership (orthogonal) TFP component directly within the production function framework. Furthermore, by specifying interactions between foreign ownership and a host of other variables, this approach is highly informative of the specific sources of the foreign-ownership effects on total factor productivity, which may prove useful in the analysis of mechanisms and in policy design.

Tybout and Westbrook's (1995) meticulously estimate productivity measures for 19 industry groups and use non-parametric correlation to test the association between the (residual) portion of productivity not explained by scale or share

[3]In the data used in this study, "foreign ownership" is defined to mean an interest of 15 per cent or more in a plant's stock equity.

shifts and exposure to trade. López-Córdova (2003) exploits the time dimension of his plant-level longitudinal sample to estimate plant-level measures of total factor productivity, against which he regresses measures of trade openness and foreign direct investment.

This study does not correct for the bias introduced by the endogeneity of the foreign ownership decision. The literature on foreign direct investment argues that weak domestic capital markets, technological or institutional factors eroding competitive conditions in the markets, informational asymmetries, and other various constraints make it difficult for domestic investors to tap the same opportunities available to foreign investors.[4]

Thus, it is plausible to think that the decision of foreign investors to acquire or hold equity of a manufacturing plant in Mexico must be related to its TFP or, at least, to its observable components. As a result, the endogeneity of foreign ownership must bias the estimation. This is a deficiency shared with a number of empirical studies on the topic. Blomström (1988) makes due note of this simultaneity bias, but does not alter his test to correct for it. Tybout and Westbrook (1995) admit in their conclusions that their measures of trade openness are endogenous to their efficiency measures, but do not adjust them as a result. López-Córdova (2002) uses NAFTA's agreed-upon tariffs for Mexico to instrument the country's actual tariffs using Olley and Pakes' (1996) algorithm, but that algorithm only corrects for the endogeneity of the input choices. The endogeneity of his foreign direct investment regressor is not addressed.

In fact, Olley and Pakes (1996) is one among various approaches advanced in the literature to correct self-selection bias. Ultimately, all of them require that, first,

[4]Caves (1971) and Caves (1974) provide the canonical arguments.

the foreign ownership decision be instrumented using some adequate variable in the data set (e.g. foreign direct investment) and, then, that the predicted variable be used to estimate the effect of foreign ownership on TFP.[5] However, the census data set made available for this study did not have adequate instruments. Data on foreign investment was missing. And even data on gross capital investment was only available for 1998. Having said that, the importance of this bias should not be exaggerated. On the basis of recent studies that use the Olley-Pakes' approach or some of its variants, it is clear that the interpretation of the results should be restrained. But it is not equally clear that the endogeneity bias is large enough to invalidate the results altogether.[6]

2.3 Context

This section starts with a brief overview of the Mexican economy in the 1990s, emphasizing the policy changes introduced in the period. It ends with a more detailed description of the conditions in the manufacturing sector using this author's calculations based on the census data.

2.3.1 The Mexican economy in the 1990s

In the mid- to late 1980s, in the midst of a severe economic stagnation that stretched over half a decade, Mexico set out to re-order its public finances, privatize a number of public companies, rein on inflation, simplify business regulations, remove barriers to trade, and attract foreign investment.

In 1986, Mexico joined the General Agreement on Tariffs and Trade (GATT) and, during the next two years, dramatically reduced its import quotas, and lowered its tariffs.[7] In 1988, it reduced and restructured its foreign debt. In 1993, it

[5] Amemiya (1984) suggested the approach.
[6] See Djankov and Hoekman (2004).
[7] Generalized Agreement on Tariffs and Trade (1993), Ten Kate and De Mateo (1989), and Ten Kate (1992).

reformed its law on foreign investment and ownership, greatly expanding scope and opportunities for foreign investors. In 1995 and 1996, the law was slightly amended to further relax some of its provisions. In 1994, Mexico put into effect the North-American Free Trade Agreement (NAFTA) with the United States and Canada, followed by the implementation of a series of minor bilateral trade agreements with other countries.

These changes induced a large inflow of foreign direct investment (FDI) in the period. Between 1986 and 1993, overall FDI expanded at an average annual rate of 27.3 per cent, while the portion of FDI that went into the industrial sector (manufacturing, construction, mining, and gas-and-electricity) grew at an average annual rate of 26.0 per cent.[8] In late 1994 and 1995, the country experienced a virulent balance-of-payments crisis and foreign investment fell precipitously. FDI destined to the manufacturing sector fell by 21.5 per cent between 1994 and 1995. It then recovered at an average 1996-1998 annual rate of 11.2 per cent. FDI in manufacturing, on the other hand, dropped by 21.7 per cent between 1994 and 1995, and then recovered at an average 1996-1998 annual rate of 5.8 per cent.[9] Tables 2.2.1 and 2.2.2 in Appendix 2 provide a summary of the economic conditions in the 1990s in Mexico.

In the ensuing debate on economic policy, the policy changes aimed to removing barriers to trade and easing the legal restrictions on foreign investment were advanced initially as a temporary expedient to *stabilize* the finances in the public and foreign-exchange sectors, and regain access to sorely needed foreign capital. The subsequent large inflow of foreign investment appeared to validate the approach. Gradually, the argument was broadened and the reforms were presented as a long-

[8]INEGI, BIE, www.inegi.gob.mx.
[9]Ibid.

run, *structural* necessity to foster economic efficiency, productivity growth, and – ultimately – social welfare.[10]

2.3.2 Mexico's manufacturing in the 1990s

Although dramatically interrupted by the peso crisis in 1994 and 1995, in the early 1990s and late 1990s, Mexico's manufacturing sector experienced a strong expansion, pulling along the whole economy.[11] On the domestic front, encouraged by the simplification and streamlining of tax- and administrative regulations, a large number of domestically-owned, small and medium-sized manufacturing plants were started up – just as old, previously informal manufacturing plants came out into the legal open.

On the foreign front, the changes in economic policy attracted large inflows of foreign investment that fed the sector's expansion. On the downside, during the 1994-1995 peso crisis, foreign investment contracted faster than domestic investment. All in all, one of the engines of this process was the *maquiladora*: a mostly foreign-owned, manufacturing plant specialized in the assembling, for direct export, of imported, duty-free intermediate inputs, using also imported "in-bond" capital equipment, and allowed under a special fiscal regime to limit its federal income tax liability to the value added domestically. Originally, the *maquiladoras* were introduced in the northern-border areas in the 1960s, but they experienced a remarkable boom in the late 1990s.[12]

Altogether, between 1988 and 1993, according to the census, the total number of manufacturing plants doubled (96.6 per cent five-year change). Between 1993 and 1998, reflecting the adverse effect of the peso crisis, the five-year percent change

[10] SPP (1989).

[11] See Tables 2.2.1 and 2.2.2 in Appendix 2.

[12] Buitelaar and Padilla Pérez (2000) (section I) provide a detailed description of the historical evolution of *maquiladoras* in Mexico.

was "only" 29.6 per cent.[13] As for the foreign-owned share of the total number of manufacturing plants, in the first five years of the period, it did not lag far behind the rest of the sector (1.1 per cent in 1988 versus 0.97 per cent in 1993). Foreign investment targeted a few industries, concentrating further in the basic metallic and (to a lesser extent) chemical industry groups. Then, in the second five years, the share of foreign-owned plants recoiled under the impact of the 1994-1995 crisis (to 0.82 per cent in 1998).

In the first five years, real gross value added per worker increased by 40.1 per cent and declined by 10.8 per-cent in the second part of the decade. In turn, capital productivity increased in the 1988-1993 period by 52.2 per cent and declined in the 1993-1998 period by 15.8 per cent. Capital intensity declined by 7.6 per cent in the first period, reflecting the explosive growth of labor-intensive start-up plants and the regularization of previously informal, equally labor-intensive, manufacturing ventures. It then increased by 5.8 per cent in the last five years. The ratio of white- to blue-collar workers, a measure used in this study to proxy the quality of labor, declined by 3.1 per cent in the 1988-1993 period and fell again by 19.3 per cent in the 1993-1998 period. On average, the size of plants (workers per plant) fell by almost 20 per cent between 1989 and 1993, and increased slightly (2 per cent) during the 1993-1998 period.

Traditionally, foreign ownership has been tied to industries with higher levels of concentration. The Herfindahl-Hirschman (H) index of concentration declined both, for the manufacturing sector as a whole by 11.4 per cent and for the group of plants where foreign ownership was predominant by 6.3 per cent during the 1988-1993 period.[14] It then increased in the 1993-1998 period: 6.3 per cent for the

[13] See Tables 2.2.3-2.2.4 in Appendix 2.

[14] The plants in a data unit of observation is "predominantly" foreign owned if at least 60 per cent of those plants are counted as foreign owned.

sector and 6.8 per cent for the foreign-owned group.[15] (See Table 2.2.5 in Appendix 2.)

By far, the industry groups with the largest share of foreign-owned plants were "Chemicals, oil products, rubber, and plastic" and "Basic metallic industries." In turn, these industry groups exhibited distinctively higher average capital-labor ratios, the largest average plant size, higher levels of industrial concentration, and comparatively modest levels of capital and intermediate-input productivity.

2.4 Methodology

This section starts with a description of the general framework used in this study, namely the estimation of an augmented Cobb-Douglas production function that embeds the foreign ownership effect and other relevant effects. Then, the specific approach used in this study, the stochastic frontier regression model, is described. Next, the discussion turns to the issue of controls and fixed effects.

2.4.1 General model

Methodologically, this study assumes that output at the unit of observation in the data set is generated by a Cobb-Douglas production function extended to embed in its total factor productivity factor the effect of foreign ownership:[16]

$$X = AL^{\alpha}K^{\beta} \tag{2.1}$$

$$A = A_0 e^{mt+\phi F} \tag{2.2}$$

[15]In this study, for a given industry (6-digit level of classification), the Herfindahl-Hirschman index of industrial concentration is defined as the sum of the squares of the market shares of the plants in each state. That is $H \equiv \sum_i S_i^2$, where S is the share of total gross output produced by the data unit of observation i. If a single state produces the whole of the industry's output, $H = 1$. As the number of states producing an industry's output increases, H approaches zero.

[16]Plant-level data is restricted due to the census' confidentiality policy. Firm-level data is not available. For a given census year, the unit of observation in the data set is a group of manufacturing plants aggregated by industry (at the 6-digit level of classification) broken down by state. Including the federal district, Mexico has 32 states and the median number of plants in the data's cross-sectional unit of observation is 12.

where X is value added (gross of depreciation), A_0 the base level of TFP, m the trend, t the census year, F a measure of the degree of foreign ownership in the unit of observation (percentage of "foreign-owned" plants)[17], ϕ the parameter capturing the effect of foreign ownership on TFP, L a measure of labor input (number of workers), K a measure of capital input (the stock of net fixed assets), and α and β are the output/input elasticities of, respectively, labor and capital (assumed to be strictly positive).

In log form,

$$\ln X = \ln A_0 + mt + \phi F + \alpha \ln L + \beta \ln K \tag{2.3}$$

In turn, the TFP effect is further specified with fixed effects to control for differences in industry group and location (state), and to capture interaction effects between foreign ownership, on the one hand, and input use, industry group, state, census year, and other controls, on the other hand. In this study, industry group, time, and location effects are specified exponentially whereas other controls are specified as factors.[18]

2.4.2 The average production function

With the census data, the previous equation (and suitable extensions) can be estimated using ordinary least squares (OLS). To keep the notation lean, let $a \equiv \ln A_0$, $\rho\Phi \equiv mt + \phi F$ and $j = 1, 2, \ldots, 64$ (32 states by 2 census years), the model to be estimated is:

$$\ln X_j = a + \alpha \ln L_j + \beta \ln K_j + \rho\Phi + u_j \tag{2.4}$$

[17] The foreign ownership variable in the data set is the aggregate for each state of an underlying binary variable that indicates whether or not a given plant is "foreign owned." A plant is designated as "foreign owned" if at least 15 per cent of its equity interest is held by a foreign individual or legal entity.

[18] In other words, in the estimated log form, industry group, time, and location enter linearly whereas other controls enter logarithmically. This specification of the controls follows Blomström (1988).

OLS uses the data (X_j, L_j, K_j, F_j), and the Gauss-Markov assumptions to estimate the parameters (a, α, β, ρ) and the errors u. That is, the OLS predicts the following X_j (the hat means predicted or estimated):

$$\hat{X}_j = \hat{a} e^{\hat{\rho}\Phi_j} L_j^{\hat{\alpha}} K_j^{\hat{\beta}} \tag{2.5}$$

The actual (observed) X_j is then:

$$X_j = \hat{X}_j e^{\hat{u}_j}. \tag{2.6}$$

In this approach, $\hat{\rho}$ is the estimate of the vector (t, ϕ), where t reflects the fixed year effect (growth rate of TFP) and F the effect of foreign ownership on the TFP level.

2.4.3 The frontier production function

Under an alternative specification, using stochastic frontier regression, A is defined as:

$$A = A_0 e^{\rho\Phi + v - \omega} \tag{2.7}$$

where $e^{-\omega}$ is interpreted as an efficiency parameter (distance to the frontier) with its minimal value converging to 0 very rapidly as ω increases (formally, as $\omega \to \infty$) and its maximal value being 1 when $\omega = 0$; and e^v is thought of as a regular random error. The log of the efficiency parameter $(-\omega)$ is assumed to be half normal on the positive side with mean zero and given variance. The error term v is assumed to be normal with mean zero and given variance. Both errors are assumed to be uncorrelated. More formally,

$$v_j \sim N(0, \sigma_v^2) \tag{2.8}$$

$$\operatorname{cov}(v_j, \omega_j) = 0 \tag{2.9}$$

$$\operatorname{cov}(v_t, v_{t+k}) = 0 \tag{2.10}$$

$$\text{Half normal: } \omega_j \sim N^+(0, \sigma_\omega^2) \tag{2.11}$$

Note that, unlike other frontier models (e.g. *data envelopment analysis* or *random coefficient regression*), the estimated "frontier" here does not envelope all the observed levels of X, including all the highest. The maximal observed values are not assumed to define the maximal level of X. That's because of the normally-distributed random shock v with mean zero. Intuitively, one can think of the curved hyper-surface fitted on the data as cutting across the cloud of points, although rather close to the upper contour delineated by the highest points.

Aigner, Lovell, and Schmidt (1976) – following Marshack and Andrews (1944), Zellner, Kmenta, and Drèze (1966), Aigner and Chu (1968), and Timmer (1971) – suggest interpreting ω as reflecting "factors under the firm's control, such as technical and economic inefficiency, the will and effort of the producer and his employees, and perhaps such factors as defective and damage product." On the other hand, v, the stochastic frontier random error, reflects "favorable as well as unfavorable external events such as luck, climate, topography, and machine performance" as well as "errors of observation and measurement."[19]

The Zellner, Kmenta, and Drèze reinterpretation amounts to assuming that the input demands are independent of the error term in the model. The random errors included in the model may affect output and profit levels *ex post*, but they do not influence the input demands *ex ante*. In this essay, due to the lack of adequate instruments for foreign ownership in the data set, the assumption of exogeneity is extended to the foreign ownership choice itself. In other words, it is assumed that the foreign ownership choice (i.e. the decision of foreigners to hold equity in Mexican manufacturing plants) is exogenous.

[19] Aigner, Lovell, and Schmidt (1976), p. 6.

Admittedly, this is a controversial stance. If the error term and the regressors (not only the input choices, but the foreign ownership choice as well) are interdependent, then all the regression estimators are biased. Not only the estimated input/output elasticities are biased, but so are the estimated TFP effects. It must be said, however, that this deficiency is common in the literature on TFP effects, a deficiency that should give pause when interpreting any estimate of specific TFP effects.

The model to be estimated is:

$$\ln X_j = a + \alpha \ln L_j + \beta \ln K_j + \rho \Phi_j + v_j - \omega_j \tag{2.12}$$

The maximum-likelihood (ML) estimator uses the data (X_j, L_j, K_j, F_j), and the assumptions above to estimate the parameters (α, β, ρ) and the errors v and ω. That is, ML predicts the following X_j (the tilde means predicted or estimated):[20]

$$\tilde{X}_j = \tilde{a} e^{\tilde{\rho}\Phi_j - \tilde{\omega}_j} L_j^{\tilde{\alpha}} K_j^{\tilde{\beta}} \tag{2.13}$$

The actual (observed) X_j is then:

$$X_j = \tilde{X}_j e^{\tilde{v}_j}. \tag{2.14}$$

In this approach, $\tilde{\rho}$ is the estimated growth of TFP. The point of this approach is to estimate also an efficiency parameter (distance to the frontier) as $e^{-\tilde{\omega}}$. And, again, $\tilde{\rho}\Phi = \tilde{m}t + \tilde{\phi}F$.

A comparison of the OLS and ML estimators (under their different assumptions about the distribution of the error terms) is beyond the scope of this essay. The following equation shows the general relationship between the two regression approaches to estimating the production function (*average* and *stochastic frontier*)

[20] OLS yields a biased estimate of a. The ML estimator is unbiased and efficient in all the parameters. See Aigner et al. (1976) and Aigner et al. (1977).

using the same data:

$$\hat{X}_j e^{\hat{u}_j} = \tilde{X}_j e^{\tilde{v}_j} \tag{2.15}$$

That is,

$$\hat{a} e^{\hat{\rho}\Phi_j + \hat{u}_j} L_j^{\hat{\alpha}} K_j^{\hat{\beta}} = \tilde{a} e^{\tilde{\rho}\Phi_j + \tilde{v}_j - \tilde{\omega}_j} L_j^{\tilde{\alpha}} K_j^{\tilde{\beta}} \tag{2.16}$$

Absent a full system of equations to solve for each parameter under SF in terms of the corresponding parameter under OLS, all that can be said in general is rather obvious, i.e. that the sources of discrepancy in the estimated parameters result from either the different assumptions of the estimators or from the different specification of A to include the efficiency parameter.

2.4.4 Fixed effects and controls

One brief note about fixed effects. It would have been better to include industry fixed effects at the 6-digit classification level. Typically, in the empirical estimation of production functions, industry differences tend to be comparatively large. However, the industrial classification used by the manufacturing census changed significantly, especially between 1994 and 1999, as Mexico phased out its traditional industrial classification and adopted the North American Industrial Classification System (NAICS) common to Canada and the United States, agreed upon under NAFTA. Matching 6-digit industries between the 1994 and the 1999 census would have entailed many arbitrary decisions. Or, if all 6-digit level industries from both census years had been included, the sacrifice of degrees of freedom would have been considerable. As a compromise, industry fixed effects were included but only at the 2-digit level (industry group).

Among the controls used in this study, plant size (proxied here by the number of workers per plant for a given unit of observation) requires an special comment. The argument included in the estimated production function is the number of workers.

To make the point at its simplest, consider the following model of the average production function:

$$X_j = A_j L_j^{\alpha} K_j^{\beta} \tag{2.17}$$

$$A_j = A_0 S_j^{\zeta} e^{mt+\phi F_j} \tag{2.18}$$

where $S \equiv L/N$ is plant size measured as workers per plant. That is, the following equation in logarithmic form is estimated:

$$\ln X_j = \ln A_0 + \gamma \ln L_j + \beta \ln K_j - \zeta \ln N_j + mt + \phi \Phi_j \tag{2.19}$$

with the restriction:

$$\gamma = \alpha + \zeta \tag{2.20}$$

It is possible to recover α from the restriction: $\alpha = \gamma - \zeta$.

Alternatively, estimate the following unrestricted equation in logarithmic form:

$$\ln X_j = \ln A_0' + \gamma' \ln L_j + \beta' \ln K_j - \zeta' \ln N_j + m't + \phi' \Phi_j \tag{2.21}$$

An F test helps to determine whether there is a significant difference between γ and γ'.

This is the only non-trivial issue related to the inclusion of controls. In addition to plant size, W, an index of the quality of the labor input proxied by the ratio of white-collar to blue-collar workers, and H a Herfindahl index of industry concentration are included as well. In other words, the estimated equation in logarithmic form is:

$$\begin{aligned} \ln X_j = \ln A_0 + \zeta \ln N_j + \lambda \ln W_j + \iota \ln H_j \\ +mt + \phi \Phi + \gamma \ln L_j + \beta \ln K_j \end{aligned} \tag{2.22}$$

This completes the section.

2.5 Data and data issues

This section begins with a description of the data sets used in the study.[21] It ends with a discussion of issues that arise when the data is adjusted for inflation.

2.5.1 Census data

The main data set contains data collected in the manufacturing censuses of 1989, 1994, and 1999. The basic observational unit in the census is the establishment (plant, for short) in industries at the 6-digit industrial-classification level.

However, due to an amendment to the 1983's law on statistical and geographical information, the publication of "nominal or individualized" data is prohibited. As a result (to preclude the individual identification of plants) the unit of observation in the data sets made available for this study is an industry (6-digit level of classification) broken down by state. Including the federal district, Mexico has 32 states.

The distribution of the number of plants per unit of observation is positively skewed, with the bulk of the observations on the left hand side and a small number of high values on the right hand side. The median number of plants per unit of observation was 11 in the 1989 data set, 14 in the 1994 set, and 12 in the 1999 set. This suggests that, although the aggregation masks some of the variation at the plant level, the data by industry and state is reasonably informative of plant conditions.

[21] The Instituto Nacional de Estadística, Geografía e Informática (INEGI), in collaboration with the Sistema de Administración Tributaria, the Banco de México, the Secretaría de Economía, and the Secretaría de Hacienda y Crédito Público, implements three periodic instruments to measure the country's manufacturing activity: (1) the manufacturing census, (2) the annual manufacturing survey, and (3) the monthly manufacturing survey. The census, conducted every five years, intends to account for all manufacturing activity in the country. In turn, the annual and monthly surveys keep track of a select sample of about 6,600 of the largest plants in industries considered to be of the "highest importance." Although the surveys' samples are drawn on the basis of the results from the previous census, the results from these instruments are not necessarily consistent with one another, nor are they reconciled in any way.

The number of observations in the 1989, 1993, and 1999 data sets are 5,036, 5,664, and 7,463, respectively. Although the data is available by industry (6-digit level of classification), the industrial classification changed from census year to census year. The most drastic modification was introduced between 1994 and 1999, to conform to the North-American Industrial Classification System (NAICS), as agreed under the North-American Free Trade Agreement (NAFTA). The number of manufacturing industries was augmented from 304 and 303 in 1989 and 1994, respectively, to 395 in 1999. For this reason, this industry level was used in this study only to compute the Herfindahl-Hirschman indices of industrial concentration.

The variables in the data sets used in this study include, by unit of observation, the number of plants and the number of foreign-owned plants; overall paid personnel, blue-collar workers, white-collar workers, and other personnel; intermediate inputs, gross value added, gross output, and fixed assets net of depreciation (book value).[22] All the monetary variables in the original data are in current thousands of Mexican (new) pesos.[23]

Also as a result of the provisions in the statistical information law, the INEGI data sets record a missing value in the number of plants (N) and in the number of foreign owned plants (FO) whenever the values are lower than 3: 47.6 per cent of the observations in the 1989 census, 40.9 per cent in the 1994 census, and 40.1 per cent in the 1999 census. Not to give up almost half of the information in the data sets and, by the same token, to gauge the sensitivity of the results to alternative possible values in these variables, the regressions were also run replacing the missing values of (N, FO) with the alternative values $(2, 0)$ and $(2, 2)$. The alternative ('floor' and 'ceiling') values of FO effectively bound any possible (unknown) values

[22] In the data, "foreign ownership" is defined to mean an interest of 15 per cent or more in a plant's stock equity.

[23] Effective January 1993, the Mexican government decreed the re-denomination of its currency, whereby one New Peso became equal to one thousand Old Pesos.

of N and FO, since – again – the confidentiality threshold is 3 plants per unit of observation. The results of the regressions with these alternative values are available upon request.[24] See Table 2.5.4 in Appendix 2 and also the discussion in Section 2.5 below. These results do not alter the conclusions.[25]

2.5.2 Deflators

All monetary variables (gross value added, gross output, intermediate inputs, and net fixed assets) are in current thousands of (new) Mexican pesos. The results reported by this study are based on the deflated values of these variables (constant 1988 Mexican pesos).

Gross value added and gross output, for each industry group, were deflated using the annual averages of the price indices for 1988, 1993, and 1998 that are implicit in the statistics of physical output published by the INEGI on the basis of the monthly manufacturing survey.[26] The deflators for net fixed assets and intermediate inputs are the corresponding producer's price indices compiled by the Banco de México.[27]

The deflators are not necessarily consistent with the census data. Typically, when the census data are deflated (with deflators derived from the surveys and the Banco de México price indices), the census underestimates the growth in physical output compared to the surveys – or, which amounts to the same thing, the surveys overestimate it compared to the census. Yet another way to say this is that, implicitly, the deflated census data overestimates inflation compared to the deflated survey data.

[24] It turns out that replacing missing values of N and FO with alternative values $(2, 0)$ and $(2, 2)$ only expands the samples and, therefore, only alters the (OLS and SF) estimates without interactions. Due to missing values of other variables, the largest sample with interactions is not restricted by the missing values of N and FO.

[25] However unlikely, with large nonlinearities, the other possible values, $(1, 0)$ and $(1, 1)$, could in theory yield results outside of the bounds. For this reason, regressions were also ran with these alternative values. However, the results fell within the bounds set by the extreme cases above. These results also support the conclusions. The outputs for these regressions are available upon request.

[26] INEGI, Sistema de Cuentas Nacionales, www.inegi.gob.mx/.

[27] Banco de Mxico. Indices de precios, www.banxico.gob.mx/.

With regards to this study, the issue is whether the test of the relationship between foreign ownership and total factor productivity is or is not affected by the possibility of the constant-prices data from the census being too low compared to the (unknown) "true" constant-prices data. To clarify the point, consider that, in the estimated models, total factor productivity is specified as:

$$A = A_0 e^{mt+\phi F} \tag{2.23}$$

where A is total factor productivity for a given unit of observation, A_0 is the level of total factor productivity in 1988, F is the measure of foreign ownership, and t is a census year alternative to 1988 (i.e., 1993 or 1998). In log form, the whole model is:

$$\ln X = \ln A + \alpha \ln L + \beta \ln K \tag{2.24}$$

$$\ln A = \ln A_0 + mt + \phi F. \tag{2.25}$$

where X is output, L is the labor input, and K is the capital input.

The census data on L comes directly in physical units (number of workers), comparable across time points.[28] But with errors in X and K , what assurance does one have that the estimates of A_0, m, and ϕ would be unbiased?

In the case of the OLS estimator, the intuition is clear. Each slope is the *ratio* of the covariance of $\ln X$ and each independent variable *to* the variance of the respective independent variable. And the intercept (A_0 in this case) is a function of the slopes. Thus, if the slopes are biased so is the intercept. For example, in the

[28]Usually, studies that adjust for changes in the quality of labor scale up the data by some more-or-less arbitrary factor. Similar adjustments are made to account for capacity utilization. That's tantamount to changing the units of measurement in the variables, which only changes the scale of the coefficients, without affecting the statistical distributions. Those adjustments leave the significance of the effects intact.

case of K:

$$\hat{\beta} = \frac{\mathrm{cov}(\ln X_j, \ln K_j)}{\mathrm{var}(\ln K_j)} \tag{2.26}$$

$$\ln \hat{A}_0 = \bar{X} - \hat{\alpha}\bar{\ln L} - \hat{\beta}\bar{\ln K} - \hat{m}t - \hat{\phi}\bar{F} \tag{2.27}$$

The variances of the non-monetary variables $(\ln L, t, F)$ are not modified by the deflators. But the covariances of $\ln X$ and all other variables, and the variances of $\ln X$ and $\ln K$ are affected. Thus, a first issue is whether, after deflating X, the covariance of $\ln X$ and $(\ln L, t, F)$ *and* the variances of each of these independent variables shift in opposite directions or in the same direction but at very different rates. And the second issue is whether, after deflating X and K, the covariance of $\ln X$ and $(\ln K)$ and the variance of the latter wind up far apart. It is also clear that, for "small" values of the deflators, the logarithmic transformations of X and K dampen the effect of the deflators on the estimated coefficients. But for 1998, the deflators of X and K range from 4.2 to 8.9.[29]

In this study, these issues are dealt with empirically, although – admittedly – not necessarily settled in general. All the parameters are estimated both on the deflated data and on the nominal data, i.e. assuming zero inflation over the ten year period. It turns out that the foreign-ownership effects (ϕ) are not essentially different in these two possibly extreme cases. The estimation results for the nominal data are available upon request. Since the issue is not whether the deflated census data exaggerate physical output, but on the contrary, whether the deflated census data implicitly exaggerate the inflation rates, then the results reported in this study appear to be satisfactory.

[29] In the case of SF regression, the intuition is more complicated.

2.6 Results

The positive foreign ownership effect on total factor productivity in Mexico's manufacturing in the 1990s reported in this study is robust to changes in model specification (without or with an array of interactions), estimator (SF or OLS), and reasonable alternatives to missing values in the number of plants and of foreign owned plants.[30] These results are displayed in the Tables 2.5.1-2.5.4 included in Appendix 2.[31]

Furthermore, the inclusion of interactions *between* foreign ownership *and* factor use, plant size, the ratio of white- to blue-collar workers, an industry concentration index, census year, state, and industry group scales up the main foreign-ownership coefficient by a factor of 7. See Tables 2.5.1-2.5.3. The interaction coefficients reveal the sources of the reinforcement of the direct foreign-ownership effect.

For a given estimator, the coefficients and levels of significance of regressors other than foreign ownership remain largely unaffected by the inclusion of the interactions. On the other hand, the interactions between foreign ownership and the states are not significant. This is shown in Table 2.5.3. In the case of the industry groups, the interactions with foreign ownership turned out negative (see Table 2.5.2) whereas in the case of plant size, quality of labor, and industry concentration the interactions are positive.

[30] Remarkably, this study also finds that total factor productivity in Mexico's manufacturing decayed significantly in the two five-year periods covered. The decay in TFP from census year to census year shows to be robust to alternative model specifications, assumptions regarding the missing values, nominal vs. deflated monetary values, and estimation approaches. At first sight (although not necessarily), these results contradict claims made in the literature based on the analysis of manufacturing survey data (Tybout 1995, López-Córdova 2002, and Paus et al. 2003). However, the specific goal of this study is not the estimation of the trend of TFP in Mexico's manufacturing in the 1990s. Sorting out the extent to which these particular results are plausible, reflect measurement errors in the census, or arise from limitations in the methodology requires a more detailed investigation outside the scope of this study.

[31] The main results are also robust to measurement errors in the deflators of the nominal monetary values. For a discussion of this issue, see subsection 2.4.2.

Just as interesting is the fact that the census years, interacted with foreign ownership, have a positive and significant effect – slightly greater in the case of 1998 than 1993 (1988 is the base year). In the context of negative and significant census-year fixed effects (with and without interactions) for the manufacturing sector as a whole (greater in positive value for 1998 than 1993), these positive interaction effects with foreign ownership point to *a growing divergence* in the total factor productivity evolution between domestically-owned and foreign-owned manufacturing plants in Mexico during the decade.

Looking at the results as a whole, it is clear that the substantial extra *punch* picked up by the main foreign ownership effect when interactions are included stems from the strongly significant and *negative* interaction between foreign ownership and capital use in combination with the typically negative interactions between foreign ownership and industry group.

Given the base industry group (food, beverages, and tobacco), the pattern of interaction between foreign ownership and industry group is unclear. The interactions with all industry groups are positive and mostly significant (with the SF estimator assigning more power to these effects). Interestingly, only weakly significant under both estimators is the industry group with the largest share of foreign-owned plants, the largest capital-labor ratio, and the largest average plant size, i.e. the basic metallic industries. But the non-metallic mineral and paper, printing, and publishing industries – in groups with a foreign ownership participation below the sector's average – exhibit similar results.[32]

Not surprisingly, the differences between the results of the OLS and SF estimators are minor. The most important difference is the strengthening of the total

[32]See Table 2.5.2 in Appendix 2.

factor productivity level in the base year (1988) by a factor of 1.3, approximately. This is to be expected, since the stochastic frontier estimator shifts the estimated production function upwards, towards the maximal levels of output for each level of input (plus or minus a regular random error).[33]

Finally, as shown in Table 2.5.4., in the estimations with no interactions specified, the replacement of missing values in the number of plants and foreign-owned plants with reasonable bound values leaves the main results of this study intact. With interactions, the missing values in the interacted variables are the binding restriction on the estimated sample rather than the missing values in the number of plants and foreign-owned plants. As a result, this issue is not relevant in the case with interactions.[34]

2.7 Concluding remarks

The foreign ownership effect appears to be a positive and robust component of total factor productivity in Mexico's manufacturing sector in the 1990s. Unlike studies that leave out the indirect effects of foreign ownership on total factor productivity, this study incorporates interaction effects between foreign ownership and a host of variables. In fact – this study concludes – the direct effect of foreign ownership on total factor productivity is dramatically enhanced when the interactions are included in the estimation.

The inclusion of foreign ownership interactions in the estimations helps to reveal that, in the period covered, the productive gap between domestically-owned and foreign-owned manufacturing plants in Mexico grew significantly. This result echoes Aitken and Harrison's (1999) finding that foreign investment of plants in

[33] See the discussion in subsections 2.3.2-2.3.3.
[34] See also subsection 2.4.1.

Venezuela's manufacturing sector impacts negatively the productivity of domestically-owned plants.

Key questions about the deeper sources of the foreign-ownership effect on total factor productivity remain unanswered. In this and similar studies, any implication of causality is invalidated by the endogeneity of the foreign-ownership productivity effects in the decision facing foreign investors. The link between foreign ownership and input use, especially capacity utilization, requires further investigation. It is clear in the results of this study that, among the factors that strengthen the main foreign ownership effect, the strongly negative and significant coefficient of the capital-use interaction stands out.

In the important case of for-export *maquiladoras*, this result might be – at least partly – associated with the distinctive tax benefits of in-bond capital imports. But given the tendency of foreign ownership in manufacturing to stress product differentiation and strong branding of their products, it is difficult to look at these results without evoking a monopolistic-competition type of mechanism, with under-utilized capacity, in the industries where foreign ownership predominates.

Chapter 3

Maquiladoras and Standard of Living in Mexico Before and After NAFTA

3.1 Introduction

This essay estimates the impact across states of for-export, mostly foreign-owned assembly factories (commonly known as 'maquiladoras') on various nonincome measures of standard of living in Mexico, namely literacy rate, school enrollment rates, housing characteristics, life expectancy, infant mortality, and the modified index of human development.

The main finding of this study is that, when state and time fixed effects, and time interactions are included, maquiladora activity exhibits no discernible net influence on the measures of standard of living examined.

This works fills a vacuum in the literature on the local standard-of-living effects accompanying maquiladora manufacturing. Unlike the prevailing discursive and case studies, this study uses rigorous econometric techniques to validate its empirical claims. Unlike most previous works on the topic, this study uses census data to establish that the net maquiladora effect on non-income measures of standard of living in Mexico in the periods under study is not robustly significant.

The study covers a three-decade period punctuated by momentous changes in Mexico's economy, development strategy, and political system, including – under an evolving legislation – the transformation of the maquiladora sector into an economic powerhouse, initially confined to the border states and then extended to multiple areas in the interior.

In the late 1970s, buoyed by high oil prices and low interest rates, Mexico leveraged its oil resources in the international capital markets and grew rapidly. In the early 1980s, the drop in oil prices combined with a sharp increase in the interest rates left the country at the brink of default. The economy contracted and stagnated for over half a decade.

In the mid and late 1980s, Mexico implemented wide-ranging economic reforms. At first, the focus was on getting the public finances in order and stabilizing the current account. Gradually, the focus shifted towards the privatization of public assets, the dismantling of the import-substitution strategy of industrialization that Mexico had pursued for over thirty years, and the liberalization of foreign trade and ownership, topped by the implementation of a free-trade agreement with the United States and Canada. There was a deliberate attempt to set the country's economic course on a difficult-to-reverse 'market-friendly' or, as the critics call it, 'neoliberal' path.

In 1986, Mexico joined the GATT, reduced its import quotas, and lowered its tariffs. In 1988, it managed to reduce and restructure its foreign debt. In 1993, it reformed its law on foreign investment and ownership. In 1994, it implemented the North-American Free Trade Agreement (NAFTA) with the United States and Canada, followed by a series of minor bilateral trade agreements with other countries. That same year, in the southern and impoverished state of Chiapas, an indigenous rebelion broke out. In the spring and summer, the political system was shaken by the assassination of prominent politicians. By the end of 1994, the peso plunged. In spite of the turbulence, the peso devaluation boosted almost immediately Mexico's trade balance and enhanced the country's appeal to foreign investment.

In the late 1990s, the country experienced a boom in maquiladora manufacturing driven by a dramatic expansion in foreign direct investment.[1] Initially, the maquiladoras were clustered on large northern border towns. Gradually, they expanded towards certain areas in the central states.

Table 1.1 in Appendix 3 shows the increasing weight of maquiladora activity in Mexico's employment, gross domestic product, and exports in the 1990s, particularly in the late part of the decade. Table 1.2 shows average annual percent changes of relevant variables, which provide another view of the dynamism in maquiladora activity in the period. The accounting decomposition in Table 1.3 shows the significant and growing contribution of maquiladora activity to Mexico's total manufacturing growth in the period.

The impact of maquiladora activity on the standard of living and social welfare in the developing countries has been the subject of much controversy. Advocates have claimed that maquiladoras enhance social welfare by providing jobs, generating much needed foreign exchange, expanding the tax base and the average income, and providing external benefits like local backward and forward linkages, technology transfer, and skill spillovers. It has been argued that, although initially the effect of maquiladora activity on the environment may be harmful, over time, this tendency is reversed.[2]

In turn, critics have replied that maquiladoras offer low quality jobs, poorly paid, and substandard health-and-safety conditions. It has also been claimed that maquiladoras foster workers' exploitation, sexual and gender oppression, and abuse against migrant workers, pollute the environment, strain the public infrastructure

[1] During the 1990s, the average annual growth rate of maquiladora employment was 11.3 per cent. In the 1995-2000 period, the figure was 15.8 per cent. As a result of the peso devaluation in 1994-1995, in gross value added calculated in constant pesos (dollars), the boom was not nearly as spectacular: -4.9 (-0.3) per cent in the 1990s and -2.8 (5.9) per cent in the 1995-2000 period.

[2] See Section 4.4 below.

in the areas where they locate, worsen public health, and remain largely isolated economic enclaves with few linkages to the rest of the economy, fragmenting the economic structure and exposing it to the vagaries of the U.S. business cycle. A host of studies show that post-NAFTA economic growth, in which maquiladoras played such a prominent role (see Table 1.3), failed to narrow wage inequality and even increased it.[3]

In a recent study on the dynamics of distribution across states in Mexico, García-Verdú (2002) found that average income and non-income measures of standard of living have exhibited different paths of evolution in the last thirty years. While the states tend to converge in literacy rates, there is no evidence of convergence in infant mortality or per-capita income in recent decades. García-Verdú's study highlights the need to study separately different nonincome measures of standard of living.

High infant mortality, low life expectancy, illiteracy, low educational attaintment, and inadequate housing are generally associated with poverty.[4] Consequently, the findings reported here may contribute to the discussion on the causes and mechanisms of poverty in Mexico[5] as well as in like developing countries.

The measures of non-income standard of living used here are taken from the Population and Housing Censuses of 1980, 1990, and 2000 on literacy, school enrollment, housing characteristics, life expectancy, and infant mortality. The United Nations Development Programme (UNDP) modified index of human development, an index estimated on the basis of census data as well, is also included in the study.

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[3]See Section 4.4 below.

[4]Sen (1987) views the standard of living as a "constitutive plurality [. . .] a basket of multiple attributes, even though secondarily that basket may quite possibly be given a numerical representation in the form of an index." The creation of the Human Development Index of the United Nations Development Programme has been heavily influenced by these views. See UNDP (2003). For official poverty statistics estimated for Mexico, see Cortés Cáceres et al. (2002) and Comité Técnico para la Medición de la Pobreza (2003).

[5]See Cortés Cáceres et al. (2002) and Comité Técnico para la Medición de la Pobreza (2003).

To remove endogeneity, maquiladora activity is instrumented using a measure of road transportation time to major border metropolitan areas in the United States.[6] The latter data are supplied by the Instituto Mexicano del Transporte. To control for the effect of nonmaquiladora activity, I use average earnings also drawn from the census of population and housing.[7] The resulting IV-TSLS (OLS and GLS) regressions are estimated with and without fixed effects (both state and time). The OLS regression tests allow for robust standard errors (cluster) to correct for panel intragroup serial correlation. The GLS estimators correct for panel heteroscedasticity and autocorrelation.

When (state and time) fixed effects and (time) interactions are absent, the coefficients of instrumented maquiladora activity appear to be positive and statistically significant. However, when direct fixed effects and interactions are included in the regressions, maquiladora activity ceases to exhibit any discernible net effect on the measures of standard of living under examination. When significant, the interaction effects between time (census year) and maquiladora activity tend to be negative. Finally, GLS estimation – used to correct for panel heteroscedasticity and autocorrelation – strengthens the significance of the coefficients. However, the positive direct maquiladora effects are offset by negative, statistically significant, time interactions.[8]

This work is unique in the literature on the impact of maquiladora activity on local standards of living. It uses census data and rigorous econometric techniques to substantiate its empirical claims. Although the panel data is cross-sectionally

[6] Results of the Hausman specification tests are reported in Tables 3.5.2-3.5.12 in Appendix 3.

[7] Alternatively, for 1990 and 2000 only, I use per-capita real gross domestic product from the Sistema de Cuentas Nacionales de México or the average wage in the manufacturing industry from the industrial censuses. The data sets used, the *.do files with the Stata routines, the detailed outputs, and a whole set of additional statistics and graphs not reported on this paper will be made available by the author upon request.

[8] There is no *a-priori* justification to use random-effects estimators. See Greene (2000), p. 623, for proper criteria to use random effects.

Table 2.1. Maquiladora's economic advantages and disadvantages

	Advantages	Disadvantages
1	Direct and indirect job creation	Low-paid, exploitive, oppressive jobs
2	Foreign exchange generation	Exposure to U.S. business cycle
3	Linkages and knowledge transfer	Enclave economy
4	Environmental Kuznets curve	Environmental decay
5	Temporary regional imbalance	Increasing regional imbalance

dominated, it takes advantage of its time dimension to isolate period effects. In particular, it confronts and provides reasonable solutions to the model-specification, endogeneity, and heteroscedasticity problems of the panel data.

Section 4.4 reviews the topical literature. Section 3.3 describes the data in detail. Section 3.4 discusses the econometric issues involved. Section 3.5 presents and discusses the main results. Section 4.5 concludes and suggests avenues for further research.

3.2 Literature Review

In the 1980s and early 1990s, there was an intense debate on the impact of maquiladora activity on social welfare in Mexico. The debate on maquiladoras intersected, but did not entirely coincide with, the larger controversy on the welfare effects of trade liberalization and overall policy reform in Mexico.[9] Table 2.1 summarizes the economic advantages (A) and disadvantages (D) attributed to maquiladoras by advocates and critics.[10]

This table can be used as a reference framework to introduce some of the relevant literature. Note, however, that this study is not a direct test of the plausibility of the

[9]There are several detailed descriptions of the historical evolution of maquiladoras in Mexico. For a good overview, see Buitelaar and Padilla Pérez (2000), section II.

[10]The items listed are not necessarily mutually exclusive or collectively exhaustive. For each row, the items in columns A and D do not necessarily constitute conflicting claims. For a detailed inventory and discussion of the economic advantages and disadvantages of maquiladoras, see Fatemi (1990), a compilation of articles by several authors.

claims in Table 2.1. The goal here is to highlight (explicit or implicit) mechanisms by which maquiladora activity impacts the local standard of living, their implied algebraic sign and magnitude, as reported in previous works and – in that context – place this study.[11] At the end, two strands of the literature on Mexico's economic reforms that are related to my study are briefly discussed: (1) the relation between NAFTA and the maquiladora boom in the late 1990s and (2) the empirical work on wage dispersion after NAFTA.

Evidently, item A1 in Table 2.1 implies a mechanism and a positive economic impact. To my knowledge, there are no estimates of the welfare (or, say, GDP) multiplier effects induced by the maquiladoras value added: wages and salaries, purchases of local supplies, and taxes. According to data from Mexico's Instituto Nacional de Estadística Geografía e Informática's (INEGI) Banco de Información Económica (BIE), in 1990 only 1.3 per cent of gross output and 5 per cent of value added came from locally-supplied (nonlabor) inputs. In 2000, these figures were 2.3 per cent and 10 per cent respectively. Estimates of the proportion between direct maquiladora jobs and the 'indirect jobs' induced by the maquiladoras vary. For example, Carrillo (1997) estimated that 80 per cent of maquiladora jobs are direct jobs. On the other hand, Guajardo (1992) estimated that indirect jobs in local supplier firms is about 44 per cent of direct jobs, and jobs due to the multiplier effect of maquiladora wages are about 73 per cent of direct jobs.

In a related comparative study using pre-NAFTA data, Aitken, Harrison, and Lipsey (1995) found "no evidence of wage spillovers leading to higher wages for domestic firms" induced by foreign investment in Mexico and Venezuela. The authors provided a host of possible explanations for this phenomenon.[12] While the

[11]Some of the works discussed in this part of the section refer to experiences in maquiladoras outside of Mexico.
[12]It would be interesting to update this study to include the post-NAFTA years.

migration of some of the benefits across states cannot be ruled out, the first-order (and perhaps largest) impact is likely to be local. In this regard, the goal of this study is to quantify the effect that direct maquiladora employment has on different nonincome measures of the local standard of living, something that – to my knowledge – has not been done before.

Item D1 raises a rather complicated argument about the meaning of the concepts 'exploitation' and 'oppression.' Sargent and Matthews (1999) interpreted these charges as meaning that maquiladora jobs are "less attractive" (e.g., offer lower wages and poorer working conditions) than prior jobs held by maquiladora workers (or than alternative available jobs). These authors conducted a simple questionnaire survey on a sample of 59 maquiladora workers in Ciudad Juárez and Chihuahua and concluded that maquiladora jobs are "attractive employment for the economically disadvantaged in Northern Mexico."

Ver Beek (2001) surveyed a "random sample" of 270 maquiladora workers in the Departamento de Cortés, Honduras and compared their responses to those of 149 first-time maquiladora job applicants. The author found that maquiladora workers in the area are significantly better paid and "perceive themselves as politically more powerful and with better household relationships" than the control group. The author also found that workers at the maquiladoras feel that "they may be endangering their health" and "are less likely to be able to form a union." Workers and applicants did not exhibit significant differences in their self-perception of "overtime work," "stress," "mistreatment by supervisors," crime victimization, "ability to find child care and continue their education." The author suggests that, given the demand for maquiladora jobs in that region of Honduras, the workers must assign a larger weight on higher pay and the feeling of empowerment than on health risks in their choosing to search for work at the maquiladoras.

While the former studies (especially Ver Beek's, considerably more careful in its methodology and tempered in its claims) are worthy of attention, their authors do not do justice to the subtlety of the critics' argument. For instance, some of the criticism of the social effects of maquiladora activity comes from the Marxist intellectual tradition and, in that tradition, the term 'exploitation' does not necessarily mean an increasing or even a constant level of abuse, underpayment, poor working conditions, or mistreatment of workers, although neither of those events would be ruled out.[13]

In the case of item A2, the local benefits are difficult to identify, since they would be channeled through the strengthening of the country's balance of payments and, thereby, the macroeconomic environment. Item D2 does not imply that there is no positive impact on the local standard of living. The charge appears to be more subtle: that reliance on maquiladora activity commits the local economy to a certain path that, compared to alternative ones, is unnecessarily volatile. For a given growth rate in the average standard of living, economic volatility has been linked to a more regressive distribution. But, this econometric study cannot directly support or contest this claim, because it does not allude to any relevant counterfactual.

[13] A thorough discussion of this issue is beyond the scope of this paper, but suffice it to say that, in the tradition of Marxism, the notion of 'exploitation' is not incompatible with improving working conditions, real wages, and standards of living for the workers, not to mention an increasing local average standard of living. See, for example, Marx's (1970) description of the mechanism of 'relative surplus value production.' On the other hand, the feminist economic literature does not claim that gender or sexual oppression is incompatible with an improving standard of living for female workers. Thus, the effect of gender or sexual oppression on the local standard of living pointed by the critics is not unambiguous. See, for instance, Fontana, Joekes, and Masika (1998). Salzinger (2003) analyzes the gradual "de-feminization" of the maquiladora labor force, from the socialist feminist perspective (according to INEGI BIE data, in 1990, over 60 per cent of plant workers were female; in 2000, about 55 per cent). The importance of the gender dimension in assessing the social impact of maquiladora activity is undeniable. However, for the discussion on maquiladora workers' exploitation and gender oppression to be directly relevant to this paper, the critics would have to specify unambiguously its implication on the local standard of living, quantitatively (magnitude of change) and/or qualitatively (direction of change). I have no knowledge of such specification and, to that extent, the results presented in this paper can neither validate nor reject their claims.

As for the claim itself, that maquiladoras increase volatility in the local economy, Hanson (2002) has pointed out that “maquiladoras tend to be very sensitive to business cycles in other countries” (mainly the U.S., almost exclusive destination of maquiladora exports) and “are footloose establishments that can easily relocate to another country if local costs rise.” The same author adds that maquiladoras “may increase the sensitivity of an economy to global shocks.” While this insinuates an extra predictor in the regression equations in this study, namely some measure of dispersion in maquiladora activity over a relevant prior period, this was not not included. This type of analysis will have to wait for further research.

Items A3 and D3 refer to the long-run benefits of a more integrated, dynamic, and balanced economic structure (or the opportunity costs that result from the lack of such an structure). Based on a wide survey of various segments of the pre-NAFTA maquiladora sector, Wilson (1992) described in detail the nature and limited size of maquiladora linkages. Wilson suggested that, with adequate incentives induced by public policy, locally-owned maquiladoras are more likely to expand their local linkages than foreign-owned assembly plants, particularly those of the newer generation. She added that “If the Mexican government is to turn the maquiladora industry into a catalyst for domestic development, it must develop geographically and sectorally specific policies for increasing the maquiladoras’ local linkages.”

Following up on early claims made by Blomström and Persson (1983) and Blomström and Wolff (1994) on the existence of productivity spillovers from foreign ownership, Fairris (2003) conducted a case study of electronics plants in Guadalajara to ascertain the existence of productive knowledge transfer. The author claims to have gained “insights into the multitude ways in which a dynamic foreign presence can lead to knowledge transfer and spillovers via training incentives.” However, as noted in Wilson (1992), the maquiladoras in the electronics segment in the region of Guadalajara are known for their comparatively larger linkages, unusual in the rest of the sector. In any case, Fairris' conjectures were not confirmed by his own econometric analysis of 1992-1999 plant-level data, where FDI presence shows no statistically significant influence on job training. The author admits that "significant knowledge transfer through worker training is by no means assured with foreign direct investment. Where foreign firms utilize very low-skilled labor, and there are few forward and backward linkages, and where the product is largely export bound – typical of export processing [maquiladora] zones – the knowledge transfer may be minimal."

Item D4 suggests mechanisms of an adverse impact of maquiladoras on the standard of living: environmental decay and health issues are clearly adverse to some of the standard of living measures used in this study. Grossman and Krueger (1991) argued that, although initially the effect of maquiladora activity on the environment may be harmful, over time, this tendency is reversed: a sort of inverted U ('Kuznets') environmental curve. On the critical side, Frumkin et al. (1995) conducted a case study documenting the deterioration of the urban infrastructure and the increasing occupational and environmental hazards caused by maquiladoras on the border zones. The data used is anecdotal and the analysis is purely descriptive. Jones (1999) conducted a household survey and reported measures of association between incidence of infectious and prenatal diseases and exposure to maquiladora pollutants on the Mexican and Texan margins of the Rio Grande Valley.

The latter two studies, as many from other social sciences on the topic, insistently point out the sociological and environmental drawbacks of maquiladora activity. Although frequently these studies rely on anecdotal evidence, resort to naive statistical analysis, and overreach with conclusions largely unsupported by the empirical evidence supplied, the social and environmental phenomena they call attention to cannot be ignored or dismissed offhand by the economists. I must note however, that whatever the theoretical and empirical merits of these claims, this study does not specify structural market models for each measure of standard of living examined and, thus, it cannot address those claims directly.

The demographic and geographical issues raised by items A5 and D5 have not been duly examined in the empirical literature. The focus of this study on the *local* effects of maquiladora activity should contribute to the examination of the full demographic and geographic dimensions of Mexico's policy reform.[14]

This completes the discussion of literature most closely related to the dispute on the economic advantages and disadvantages of maquiladoras. The following is a brief discussion of work on the implications of NAFTA for maquiladoras and on post-NAFTA increase in wage inequality.

In the early 1990s, during the debates on NAFTA, the particular implications of the trade agreement for the maquiladora legislation were unclear. On the upside, were NAFTA to be implemented, many analysts predicted a substantial increase in foreign investment following the trade agreement, and – regardless of the impact on its legislation – the maquiladora sector was poised to absorb a substantial portion of the investment flows in the short and medium run. In this sense, part of the welfare effects that NAFTA was poised to induce in Mexico would be channelled through the maquiladoras. On the downside, NAFTA would allow production-sharing operations between the U.S. and Mexico outside of the maquiladora program and the duty free advantages of maquiladoras would be generalized to nonmaquiladora manufacturing. Some authors pointed that the large amounts of foreign investment

[14] Selligson (1981) provides an early discussion of the migratory aspects of the early maquiladora program. For a recent study of the geography of economic development in Mexico, see Esquivel (2000).

expected to flow into Mexico would lead to a rapid appreciation of the peso and an increase in labor costs likely to inhibit maquiladora growth.[15]

After NAFTA was approved in the U.S. Congress, the interest in the economic effects of maquiladoras declined. In the years immediately after NAFTA, the interest shifted towards the distributional effects of the treaty itself and the economic reforms implemented since the mid 1980s. During the NAFTA debate, the advocates of the treaty fomented the expectation that the removal of trade barriers in North America would lead to a reduction in Mexico's inequality as a result of the operation of the Stolper-Samuelson mechanism. Compared to the U.S. and Canada, Mexico was clearly abundant in unskilled labor and scarce in (physical and human) capital. The initial belief was that import substitution policies had artificially propped up heavier industries at the expense of primary activities and light manufacturing.[16] In absence of large shifts in technology's factor bias, if anything like the Stolper-Samuelson mechanism was to operate, freer trade would lead to a reallocation of resources towards unskilled-labor intensive industries and away from capital intensive ones. In turn, this would lead to a decrease in the real and relative return on capital (physical and human) and an increase in the real and relative return on unskilled labor.

The empirical literature did not confirm these expectations. Cragg and Epelbaum (1996) reported an increase in manufacturing wage inequality following the

[15] For a sample of the wide range of pre-NAFTA estimates of the welfare impact of NAFTA in Mexico, see Brown, Deardorff, and Stern (1991), Hinojosa-Ojeda and Robinson (1991), Young and Romero (1991), and Kehoe (1992). For two contrasting accounts of the implications of NAFTA for the maquiladora program, see Watkins (1994) and Echeverri-Carroll (1999). For an empirical study claiming that the high growth in maquiladora activity in the late 1990s was related to the peso devaluation of 1994-1995 and not to NAFTA, see Gruben (2001). For a description of the difficulty of disentangling the positive effects of NAFTA on foreign investment and maquiladora trade from those of previous liberalization policies implemented by Mexico in the period, see Congressional Budget Office (2003), p. x.

[16] The canonical criticism of import substitution in Latin America is synthesized in Krueger (1995), where this case is made compellingly. Stiglitz (2002) strongly defends the overall record of import-substitution policies and finds the existing international monetary arrangements and misguided U.S. monetary policies to be the main culprits of the debt crisis in the region.

reforms. Their paper was followed by others confirming the basic finding: Feenstra and Hanson (1996), Feliciano (2001), Hanson (2003), among others.[17] Some authors tried to rationalize the findings by arguing that, in fact, before the reforms, Mexico's light manufacturing had been most protected and unionized. The dismantling of import substitution had weakened the bargaining power of workers thus leading to higher wage dispersion. Others (e.g., Hanson, 2003) alluded to the skill bias in the type of technological change induced by foreign investment, particularly in the maquiladora sector. Yet another plausible explanation was entirely neglected: a several-years-long lag in the operation of the Stolper-Samuelson mechanism due to plain friction reinforced by institutional rigidities in Mexico's good and factor markets.[18] The empirical literature has not addressed the impact of the 1990s' increase in wage inequality on the local standard of living.

To my knowledge, no other study has looked at nonincome measures of standard of living, such as literacy rate, school enrollment rates, housing characteristics, and health indices from the population and housing census data to estimate the local economic impact of maquiladora activity. To that extent, this study is unique.

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[17] Esquivel and Rodríguez-López (2003) reviewed the literature and contributed to it.

[18] The Stolper-Samuelson Theorem assumes that good and factor markets are perfectly competitive and that the adjustment in resource allocation following changes in good and factor prices is instantaneous and costless. Clearly, this a grossly unrealistic assumption. It is unlikely that the kind of sectoral re-allocation of labor and capital implied by the Stolper-Samuelson Theorem, a process that would entail the reversal of long-dated inertias in migratory patterns and long-run investment behavior, could take place in months rather than in decades. To illustrate the argument, consider the case of Mexico's rural economy: In spite of its shrinking share in total GDP, this sector continues to tie about one fourth of the labor force and an even higher share of the pool of unskilled labor in Mexico. Approximately half of the farm land is collectively tenured and, 12 years after a process of land tenure certification and reform (PROCEDE) was initiated to enable legal leasing and property transfer, the results have been slow to show (Zorrilla Ornelas, 2003). In particular, with NAFTA in place, PROCEDE was supposed to attract immediate investment into agriculture. Yet, between 1994 and 2000, only 0.3 per cent of the total foreign direct investment went to agriculture (0.9 per cent went to mining). In contrast, 61 per cent went to manufacturing, mostly maquiladoras, 14 per cent to financial services, and 12 per cent to retail trading (INEGI BIE). Perhaps the ultimate reason why the lag hypothesis has been neglected is that the most reliable data used in the empirical work on income dispersion comes from manufacturing.

3.3 Data

The main data set was provided by Mexico's INEGI. The data on maquiladora activity are available at the INEGI's Banco de Información Económica (BIE). Their ultimate source is the Sistema de Cuentas Nacionales de México.[19] The data on earnings of the economically-active occupied population, literacy rate, housing characteristics, and various measures of educational attainment are from the Population and Housing Censuses of 1980, 1990, and 2000. They are available at the INEGI's Sistema de Bases de Datos Municipales (SIMBAD) web site. The data on life expectancy and infant mortality, as well as migration rates, are also from the Population and Housing Censuses of 1980, 1990, and 2000, but they were provided in a separate file by the Consejo Nacional de Población (CONAPO). The data on infant mortality for 1980 were taken from Instituto Nacional de Estadística, Geografía e Informática (1989).[20]

In its narrower, more operational definition, the Index of Human Development (IHD) is conceptualized as "the set of capabilities to live a long and healthy life, acquire knowledge, and earn income." It is an equally weighted average of indices in the following three 'dimensions': longevity, knowledge, and access to resources. More specifically, the statistical indicators used in constructing the index are: life expectancy at birth (for longevity), literacy rate and elementary, secondary, and high school enrollment (for knowledge), and GDP per capita (for access to re-

[19]The estimates reported in this paper use maquiladora total payroll employment as the measure of maquiladora activity, the regressor of interest. Similar results are obtained using maquiladora gross value added, as employment and value added are highly correlated ($r = 0.95$). Adding the value added (i.e., the sum of wages, salaries, and residual earnings), or its components, as a separate regressor would have introduced unnecessary collinearity. Alternative estimates with the instrumented maquiladora value added as a regressor are available upon request.

[20]Net inter-state and international migration rates were also used as controls. The rationale is that maquiladora activity attracts migrant workers, the inflow of migrants strains the public infrastructure in the receiving states and has a direct negative impact on the standard of living, which might lead to an underestimation of the true (positive) effects of maquiladora activity on the standard of living. Although the instrumentation of maquiladora activity may remove some of the simultaneity with the migration variables (Hausman tests fail to suggest significant feedback between migration and maquiladora activity), net migration rates were included as explicit controls. The estimates are available upon request.

sources). The indicators are calculated using simple averages and normalizing the results against a scale of minimum and maximum values derived from international estimates by the United Nations Development Programme (UNDP). The MIHD ranges between 0 (international minimum) and 1 (international maximum).[21]

Maquiladora activity was instrumented with data on average road transportation times from the capital of each state to major U.S. border metropolitan areas, as estimated by the Instituto Mexicano del Transporte of the Secretaría de Comunicaciones y Transportes.[22]

The panel dimension is 32 states by 3 years (1980, 1990, 2000) for a total of 96 data points.

3.4 Econometric Issues

I begin the discussion by stating the general econometric specification. Then I turn to the issues raised by the model's specification, endogeneity, fixed effects, and heteroscedasticity, as well as the solutions proposed to deal with each of the issues.

3.4.1 General Specification

Let the following variables be indexed by state i and year t for $i = 1, \ldots, 32$ and $t = 1, \ldots, 3$:

Y: a non-income measure of standard of living,

M: a measure of maquiladora activity (per capita),

R: road transportation time from the state capital to a major border U.S. city,

$\mathbf{D}^t$: a 2-row vector of year dummies,

[21] Detailed information on the evolution of the concept and method of calculation of the IHD is available at http://www.undp.org.mx/desarrollohumano/informefr.html. The data used in this study is on the Modified Index of Human Development (MIHD). I thank Gerardo Esquivel (Colegio de México and UNDP-Mexico) for kindly making it available to me.

[22] Similar results were obtained instrumenting maquiladora activity with a widely-used seven-region classification of Mexico's states. For more on this regional classification, see Esquivel (2000). The alternate estimates are available upon request.

$\mathbf{D}^i$: a 31-row vector of state dummies , and

$\mathbf{X}$: a vector of controls.

Maquiladora activity is instrumented as follows:

$$\ln M_{it} = \alpha_0 + \alpha_1 R_{it} + \mathbf{X}_{it}\mathbf{A} + \epsilon_{it} \tag{3.1}$$

where $\mathbf{A}$ is the vector of control coefficients included in the second-step regression.

The TS pool regression model is:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln \hat{M}_{it} + \mathbf{X}_{it}\mathbf{B} + \varepsilon_{it} \tag{3.2}$$

where $\ln \hat{M}$ is predicted $\ln M$ from equation (3.1).

The IV-DV-TS regression model is:

$$\ln Y_{it} = \gamma_0 + \gamma_1 \ln \hat{M}_{it} + \mathbf{X}_{it}\mathbf{\Gamma} + \mathbf{D}^t\mathbf{\Gamma}^t + \mathbf{D}^i\mathbf{\Gamma}^i + \xi_{it} \tag{3.3}$$

where $\mathbf{\Gamma}^t$ is a 2-column vector of year dummy coefficients and $\mathbf{\Gamma}^i$ is a 31-column vector of state dummy coefficients. In general, the Greek letters denote the parameters of the model.

These models were estimated using OLS and GLS. Average (or per-capita) earnings and the growth rate of per-capita GDP in the previous 5 years were included as controls. Census year interaction effects with, respectively, maquiladora activity and average earnings were also included.

Under the assumption of equal slope coefficients by year and state, no correlation between the regressors and the error term, and zero expected value of errors, OLS is an unbiased although inefficient estimator. GLS is an unbiased estimator and is also efficient in the presence of heteroscedasticity.

Estimation statistics for these models are presented in Tables 3.2.5.2-3.5.12 in Appendix 3.

3.4.2 Model Form and Endogeneity

Structural equations modeling the markets for each of the goods involved, literacy, school enrollment, adequate housing, and health, were not postulated. Given the inherent complexity of the goods and the diverse institutional characteristics of the markets involved, identifying each market's structural parameters is too daunting a task with the data at hand. Simply, this analysis cannot identify those parameters.

That said, to the extent the market characteristics involved are local, the state fixed effects will pick them up. To the extent they are common to all states, they will be picked up by the intercept. To the extent they are varying over time, they will be picked up by the year fixed effects. And to the extent they are neither, they will be picked up by the error term (under the restriction that the expected value of all the influences bundled in the error term is zero).[23]

On the other hand, the relations between maquiladora and nonmaquiladora manufacturing or between maquiladoras and the rest of the economy are likely to be fairly complex. Thus, the first task of this study is to separate the 'pure' maquiladora effect from other effects resulting from nonmaquiladora activity. Two stories may illustrate the potential endogeneity involved:

Other things equal, investment in modern maquiladora manufacturing is likely to be attracted to areas with a pre-existing basic infrastructure in public services and a relatively educated and healthy labor force. In other words, whatever the effect of maquiladora activity on the standard of living, other things constant, maquiladora activity is likely to flow toward areas with a higher initial standard of living.

[23] So, by humbling necessity if not by conviction, I am sympathetic to Liu's (1969) classical argument that all simultaneous-equations models of the economy are truly unidentified and only reduced forms can be estimated.

On the other hand, at least during their first stages of evolution, maquiladoras were invited to the northern border towns as a response to local joblessness, which was causing a rapid deterioration in the standard of living, and immigration flows, which were overwhelming the local capacity of schools, housing infrastructure, and health services. In other words, other things equal, maquiladora activity is likely to flow toward areas with a lower initial standard of living.

Of course, both scenarios may coexist, in which case either one of them dominates or they exactly cancel each other out. In any case, the mere visual inspection of the data cannot settle the issue. I conducted Hausman specification tests on regressions with no fixed effects.[24]. The results of the Hausman tests are reported for each dependent variable.

A related issue is whether the inclusion of per-capita overall earnings as a control leads to underestimating the positive effect of maquiladora activity, since maquiladora employment is likely to exert an external positive effect on non-maquiladora wages, an effect that would be picked up by the coefficient of the control. This argument is not entirely convincing on two grounds. First, even in border states, were maquiladoras dominated local manufacturing in the late 1990s, the share of overall manufacturing in state employment and value added was never greater than 25 per cent. In most Mexican states, the weight of maquiladora employment in manufacturing and the economy as a whole was even smaller. And, second, the argument that maquiladoras have an external positive effect on the nonmaquiladora labor market begs the opposite argument that nonmaquiladora activity exercises a similar – if not larger – positive external effect on maquiladora

[24]With more regressors, in this case fixed effects, the Hausman χ^2 statistic increases monotonically and the null hypothesis of equal coefficients in the inefficient and efficient estimators is more easily rejected.

wages. In the absence of prior evidence, the assumption that the two external effects cancel each other out is not unreasonable.

Under the presumption of simultaneity bias in the standard OLS estimator, I used the IV-TSLS estimator. To instrument maquiladora activity, I used road transportation time from the capital of each state to the nearest major metropolitan area on the U.S. border. On the data, this variable is highly correlated to maquiladora activity and largely uncorrelated to the estimated residuals.

3.4.3 Fixed Effects, Heteroscedasticity, and Autocorrelation

The assumption of the pooled models – namely, that the coefficients are fixed across states and years – is too restrictive to be plausible. Thus, another key issue in isolating the 'pure' maquiladora effect was the existence of time-invariant factors characteristic of each state (i.e., the 'state effects') and factors that vary over time but are roughly common to all states.[25]

Instances of the former are geography, climate, natural resource endowments, demographics, local institutions, laws and regulations, hardwired cultural traits, and long-standing capital infrastructure. One of these time-invariant variables is the distance to the border, which is highly correlated to road transportation time or, more generally transportation costs, and thus to maquiladora investment and activity.

Since I use road transportation time to instrument maquiladora activity, I implicitly assume that the only way in which this variable affects the standard of living

[25]It may seem plausible that the changes in the policy and regulatory environment in Mexico that took place in the late 1980s and early 1990s, affected the states differently. For instance, changes in relative prices induced by trade liberalization, which presumably led to switching of resources from lower to higher profitability ventures, could have had a different impact on each region. These effects could be captured including interactive or 'differential' state and year slopes in the regression models. I did implement interactive year slopes. See column (10) in Tables 3.5.2-3.5.12 in Appendix 3. But in this panel, sparse and cross-sectionally dominated, I did not have enough degrees of freedom to afford interactive group slopes. In further research, I plan to implement regional interactive slopes.

is via its effect on maquiladora activity. Another way to frame this assumption is to say that the other time-invariant factors bundled in the state effects dominate the geographic distance element. The data bears this assumption reasonably well. In any case, this assumption seems to be a reasonable restriction to impose given the advantages of using road transportation time in the IV-TSLS estimation.[26]

Instances of state-invariant, time-variant effects are changes in national patterns of consumption, external shocks, and changes in national policy and the regulatory environment. Precisely, the three-decade period under analysis was punctuated by inflections in oil prices and interest rates in the international markets that shook Mexico's economy. To mention a few highly consequential instances: In 1982, with oil as Mexico's main export, its price in the international market fell sharply. Starting in the mid 1980s, Mexico's development strategy, roughly based on the import-substitution industrialization policies of the postwar, was thoroughly revised and replaced by a 'market-friendly,' 'export-led,' or – as the critics call it – 'neoliberal' strategy.[27]

If the assumption of state- and time-invariant coefficients is not warranted, the estimated coefficients in the pool models are biased in an unknown direction. I used the IV-DV-TSLS estimator (fixed state and year effects), which is unbiased under the assumption of different state and year intercepts. There was no *a priori* rationale to specify random effects.[28]

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[26]A similar problem arises if I use Esquivel's (2000) regional classification to instrument maquiladora activity.

[27]To this one may add the impact of the sudden increase in the interest rates in the early 1980s. Stiglitz (2002) has argued that, even if the governments and the government-owned companies in Latin America had been financially healthy and corruption had not been an issue at the time (which was certainly not the case in Mexico), the sharp increase in the rate driven by the Federal Reserve under Paul Volcker's management might have been sufficient to send the highly indebted Latin-American countries into bankruptcy.

[28]Greene (2000) states that: "The fixed effects model is a reasonable approach when I can be confident that the differences between units can be viewed as parametric shifts of the regression function. This model might be viewed as applying only to the cross-sectional units in the study, not to additional ones outside the sample. [...] In other settings, it might be more appropriate to view individual specific constant terms as randomly distributed across cross-sectional units" (p. 623). The former seems to be the case in this study. The 'units' included in the sample are all the 32 states of Mexico. There are no "additional ones outside the sample."

Panel estimates are likely to be plagued by intragroup serial correlation and, especially in the case of cross-sectionally dominated panels, heteroscedasticity, which lead to estimation bias and inefficiency in the (IV-DV-TS) OLS estimator. In this case, the GLS estimator is unbiased and efficient. The issue of efficiency is important to uphold the null hypothesis in these regressions, i.e., the maquiladora effect on each non-income measures of standard of living analyzed (except college enrollment rate) is not statistically significantly different from zero. An inefficient estimator (e.g., OLS) may be an unduly strict test on the maquiladora coefficients' significance.

Finally, the standard errors in all OLS regressions specify robust standard errors to correct for the effects of (time) serial correlation in the panel.[29]

3.5 Results and discussion

Tables 3.5.1 (a) and 3.5.1 (b) in Appendix 3 summarize the descriptive statistics for the variables involved (by state). Tables 3.5.2-3.5.12 show the estimation results.

In the following discussion, "literacy" measures the number of literate individuals in each state as a ratio of the population 15 or older in same state. School enrollment measures, e.g., elementary school enrollment rate, is the number of individuals enrolled as a ratio of the total number of individuals of appropriate school age in each state. "Housing" measures the number of houses with given characteristics per capita in each state. "Life expectancy" and "infant mortality" are the conventional measures. The "modified index of human development" is described in Section 3.3 above.

Overall, maquiladora activity was not a statistically significant predictor of the measures of standard of living examined once (1) controls (per-capita earnings and

[29]For a detailed case showing the consequences of time-series autocorrelation in panel studies on the reported t-statistics, see Bertrand et al. (2004).

prior growth rate in per-capita GDP), (2) year and state fixed effects, and (3) time interactions were included.

With no exception, in the OLS models with (group and time) fixed effects, the maquiladora effect is not statistically significant. In the GLS models with (group and time) fixed effects, but no interactions, in five (out of eleven) cases, namely literacy, elementary school enrollment, house with electric power, life expectancy, and infant mortality – do the direct maquiladora effects appear to be positive and significant. However, in the same estimation with (time) interactions, the algebraic signs of the indirect maquiladora effects offset those of the direct effects. Often, the interaction effects overwhelm the direct ones.

Otherwise in the education category, the direct and interaction maquiladora effects on secondary, high school, and college enrollment rates tend to exhibit negative algebraic signs and/or lack of significance. For house with tap water, life expectancy, and the Modified Index of Human Development the results are similar: negative effects and/or lack of significance.

In all cases but one (infant mortality), the maquiladora effect is positive and significant under the simplest, most restrictive (OLS) models.[30] The inclusion of controls alone takes away the significance of the maquiladora effect in one of the measures of standard of living examined (high school enrollment). The inclusion of year fixed effects alone erases the significance in seven (out of the eleven) measures. And, more dramatically, the inclusion of state fixed effects alone removes the significance in nine out of the eleven measures. The inclusion of both effects

[30] Compared to the other series, the data on infant mortality appears anomalous. Aside from its greater dispersion, the statistics for 1980 are strikingly at odds with those for 1990 and 2000. Neither INEGI nor CONAPO (Mexico's national population council) provides any specific explanation for, say, the dramatic reversal in the infant mortality ranking of several states. Thus, for example, in 1980, Guerrero was among the five lowest infant mortality states. In 1990 and 2000, it was among the five highest. On the other hand, in 1980, Guanajuato was among the five highest infant mortality states, yet in 1990 and 2000 it was among the ten lowest.

eliminates the statistical significance of the maquiladora effect in all of the eleven measures.

In seven cases, the GLS estimator restitutes significance to the maquiladora effect. But in four of these cases, the algebraic sign of the coefficient is negative. In nine GLS models with interactions, the interaction between maquiladora activity and census year is negative and strongly significant for at least one of the census years.

With regards to the control regressors, the direct effects of average earnings tend to be positive and strongly significant. The interaction effects are mixed. The effect of the growth rate of per-capita GDP is weaker and, more often than not, negative.

The fit of the regressions, as measured by the (adjusted) R^2 statistic, rapidly approaches 1 when the fixed effects are included, especially the state fixed effects. This suggests that, by far, the bulk of the variation in these measures of standard of living is accounted for by either factors specific to each state and relatively invariant over time or by nationwide socioeconomic events that took place at particular points in time during the period of study, other than the regressors included in the models.

The Hausman χ^2 statistics indicate that, in seven of the measures, the TSLS estimates are significantly different from those of the one stage model. In these cases, the use of instrumental variable regression appears to be helpful in correcting the endogeneity bias.

3.6 Final Remarks

This study concludes that, overall, with the inclusion of controls (per-capita earnings and prior growth rate of per-capita GDP), state and time effects, and time interaction effects, maquiladora activity exhibits no discernable net impact on the measures of standard of living under examination.

The present study is unique in the literature on the impact of maquiladora activity on local standards of living. Unlike the discursive and case studies that prevailed in the literature, this work uses rigorous econometric techniques to back up its empirical claims. Unlike any previous work, it uses census data to ascertain that the net maquiladora effect on non-income measures of standard of living in Mexico in the periods under study is not robust. Although the data panel is cross-sectionally dominated, it takes advantage of its time dimension to isolate period effects. In particular, it confronts and provides reasonable solutions to the model-specification, endogeneity, and heteroscedasticity problems of the data panel.

Having said that, cross-sectional econometric analysis is limited by the availability of disaggregated and compatible data. The data from the Households' Income and Spending National Surveys (ENIGHs), which offers more direct measures of social welfare, are not disaggregated by municipality or even state. They are only representative at the urban-rural and male-female level of disaggregation. A similar problem arises with the National Employment Surveys (ENEs and ENEUs). However, the ENEs' and ENEUs' data could be fruitfully used in combination with the data from the industrial censuses.

A strong limitation of this study is that the census data panel used only includes three years, with a 10 year gap between points (1980, 1990, and 2000). There are only usable census socio-demographic data for those three years, which makes it impossible to extend the panel data. Another limitation is the aggregation by state. The maquiladora data by municipality is restricted to municipalities with a large maquiladora activity, even though there are other municipalities with significant maquiladora activity not included in the tables. In spite of this restriction, it should be possible to test the relation between maquiladora activity and social welfare with more disaggregated data by municipality available at the INEGI's web site. That is to be pursued in the future.

More work is required to elucidate the specific mechanisms by which maquiladora activity leads to changes in social welfare, both on the theoretical and empirical sides. Finally, future research should address the impact of the volatility of maquiladora activity (and/or its dependence on the U.S. business cycle) on these measures of standard of living by state.

Chapter 4

Inequality and Growth: A Two-Player Dynamic Game with Production and Appropriation

4.1 Introduction

Empirical studies conducted on various data sets show that, after controlling for other relevant factors, larger initial economic disparities in an economy are associated with lower subsequent economic performance.[1]

Motivated by the finding of these empirical studies, this paper lays out a two-player differential game model of a simple economy with production and appropriation, determines its Markovian Nash equilibrium analytically, and examines its implications. Key insights about the dynamics of this artificial economy are gleaned from these results.

Although the nonlinearity of the Markovian Nash equilibrium's canonical system of differential equations may preclude a closed-form solution of its dynamic allocation problem, numerical solutions can be implemented. However, such numerical solutions and their analysis are outside the scope of this paper.

By *production*, it is meant that each player can use the stock of wealth under her possession to create a flow of net new wealth through a simple concave technology. *Appropriation* is defined as the set of costly actions undertaken to protect one's own possessions and/or to grab someone else's possessions.

In this context, ownership means degree of possession or disposability of wealth. In the practice of social life, legal and ethical rules, or rather the degree to which these are enforced, appear to determine ownership. But ownership in the sense used in this paper does not require legal or ethical recognition. It is entirely the outcome

[1] A summary of the ongoing empirical debate on this matter is provided in section (4.4).

of the initial distribution of possessions, technological conditions of production and appropriation, and economic outcomes (shadow prices and actions chosen optimally over time) that flow from constrained utility maximization.[2] Thus, ownership is viewed in a continuum, with different degrees of force. In this light, the extent of appropriation can be interpreted as a negative or inverse measure of wealth *excludability*, as the force of ownership is called in the theoretical literature.[3]

This model highlights the inefficiencies resulting from appropriation and, in that sense, describes a mechanism by which a skewed initial distribution of wealth may lead to distributional conflict, large welfare losses, and thereby poor economic performance.[4] But, this is hardly a surprising result. More importantly, the model provides a way to examine the effects of different economic settings – each with its corresponding system of incentives – on concurrent growth, where these economic settings can be proxied by boundary conditions and the relations among technological parameters.

In a one-period model, Grossman and Kim (1995) postulate appropriation in the form of two distinctive actions: defense (which they call "fortifications") and attack (which they call "predation"). Their specification of the appropriation function, including parameters that capture the efficacy and destructiveness (wastefulness) involved in appropriation actions, has some attractive features. Appropriation actions enter the appropriation function inversely (hyperbolically). That is,

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[2]The model includes as parameters the fraction of each player's wealth that is subject to appropriation, the "productivity" of appropriation outlays, and the fraction of the wealth taken away from the victim that winds up effectively appropriated by the aggressor. Each of these parameters can be viewed as reflecting institutional (political, legal, or ethical) conditions in the economy. However, this model does not require that. They can also be viewed as entirely determined by technology and economics.

[3]The model in this paper is consistent with both "political economy" and "social conflict" causality mechanisms as per the classification in Ferreira (1999). More generally, although the distinctions matter in practice, the concern here is not whether appropriation is conducted legitimately, lawfully (e.g., fiscal policy, eminent domain expropriation), or otherwise (e.g., blatant robbery).

[4]Other mechanisms can explain the negative relationship between initial wealth distribution and poor economic performance in the framework of a dynamic game. One such mechanism could be a players' difference in time preferences specified as different rates of subjective discounting in the payoff function.

the amount of her own wealth a player manages to retain is an increasing and smooth function of the appropriation actions she undertakes. On the other hand, the amount of player 2's wealth that player 1 manages to appropriate is a decreasing and smooth function of player 1's appropriation actions. Furthermore, the marginal products of appropriation (in the form of wealth retained and grabbed) are decreasing. Although slightly simplified, Grossman and Kim's basic set-up is adopted in the model presented in this paper.[5] In this sense, this model provides a dynamic generalization of these authors' static results.

From a welfare analysis perspective, the natural Pareto-optimal baseline is that of a cooperative dynamic game, where the players – prior to their playing the game – agree to cooperate and share the dynamic efficiencies thus gained.[6] In such case, the game effectively becomes a regular optimal control problem of the type studied in Ramsey's (1928) and Koopmans's (1965) models. However, the institutional setting that enables the players to make prior binding cooperative agreements is necessarily exogenous. At first sight, under the assumption of self-interested players, the cooperative case appears to have little practical relevance, since the institutional setting that induces cooperation is not fully explicated within the model.

The advantage of parameterizing the efficacy and destructiveness of appropriation is precisely that it allows us to explicate how such conditions may be brought about endogenously by two self-interested players in strategic interaction (e.g. individuals, classes, nations) with no *a priori* motivation to cooperate. In other words, we seek the conditions under which – given an initial distribution of wealth – self-interested players may optimally renounce appropriation actions, thus reaping

[5]The distinction between defensive and aggressive actions in Grossman and Kim (1995) is abandoned to ensure a closed-form Markovian Nash equilibrium.

[6]Also known in the literature as the "coordination game." Section 4.4 summarizes this well-known case.

and sharing the dynamic gains from cooperation, in the face of constraints in the technology and economics of production and appropriation. Grossman and Kim (1995) call this type of solution to the game a *nonaggressive equilibrium*.[7]

The theorem establishing the existence of Markovian Nash equilibria in differential games states that concavity in the controls of the Hamiltonian, which in turn requires concavity of the felicity function and of the state equation of motion, is sufficient to ensure the existence of at least one Markovian Nash equilibrium of the right sign, e.g. a "supremum" of the objective functional.[8] But, determining Markovian Nash equilibria in practice is a vexing task. In particular, nonlinear interactions between state and control variables makes it extremely difficult to obtain a closed-form Markovian Nash equilibrium.[9] This is undoubtedly the biggest analytical roadblock in solving a differential game model and deriving clear economic implications from it. This is perhaps the chief reason why this method has so far attracted limited interest among economic theorists.

The unique contribution of this paper is the specification of a model that, without sacrificing the appealing nonlinearity in the interactions between actions and wealth in the appropriation function (and, thereby, in the equation of motion and the Hamiltonian) that Grossman and Kim (1995) postulated, has a *unique* closed-

[7]In Grossman and Kim's model, the nonaggressive equilibrium case is clearly distinguished from the coordination or cooperative case, because the former requires positive defensive outlays to the point of deterring all offensive expenditures, whereas the latter needs no appropriation outlays whatsoever. In other words, the latter is Pareto optimal whereas the former is Pareto suboptimal. However, in the model in this paper, a nonaggressive equilibrium entails zero appropriation outlays, effectively exhibiting the same Pareto superior properties of the cooperative case. For this reason only, at considerable semantic cost, in this paper, the terms *nonaggression* and *cooperation* are used interchangeably.

[8]See Dockner et al. (2000) for the statement and proof of the existence theorem.

[9]In a two-player game, the Markovian Nash equilibrium is obtained from the first-order conditions for each instantaneous ("static") optimum for both players, by solving these conditions simultaneously for both players' strategies in terms of the state and costate variables and parameters. A Nash equilibrium is a strategy that maximizes the payoff of each player under the assumption that the other player simultaneously chooses her optimal strategy. For each player, a Nash equilibrium is the best response to the Nash equilibrium strategies of the other player. Markovian strategies (also called "closed-loop" or "feedback strategies") are dynamic decision rules in which the choice of a player's current action depends entirely on the current state vector and the current time. The Nash equilibrium in a game played with Markovian strategies is said to be a Markovian Nash equilibrium.

form Markovian Nash equilibrium that – in spite of its apparent complexity – yields significant insight into the economics of appropriation and growth.

Section 4.2.1 sets up the model in its more general form in the framework of a differential game. Section 4.3 analyzes the equilibrium conditions. Section 4.4 discusses relevant literature. Section 4.5 has a few concluding remarks.

4.2 Game

This section is organized as follows: Subsection 4.2.1 sets up the model. Subsection 4.2.2 finds the point-in-time conditions for an individual player's optimal path, given feasible strategies chosen by the other player. Subsection 4.2.3 determines the general Markovian Nash equilibrium of the noncooperative game.

4.2.1 Framework

Consider a single-good economy with two utility-maximizing players $i = 1, 2$ over a period from the present $t = 0$ to a terminal time $t = T$. For each player i, the payoff functional is the sum of the instantaneous utility (*felicity*) of current consumption over the (continuous time) life of the game:

$$W_i = \int_0^T u[c_i(t)]\ dt \tag{4.1}$$

$$\tag{4.2}$$

where $u'(c) > 0$ and $u''(c) < 0$. That is, felicity $u[c(t)]$ is assumed to be a continuous, smooth, increasing, and strictly concave function of current (instantaneous) consumption, which is assumed to be nonnegative. For simplicity, there is no discounting of future utility.[10]

[10]Ramsey (1928), Pigou (1932), and Harrod (1948) view the discounting of utility of future generations as ethically indefensible. Subjective discounting does not alter the overall results in this model, since the discount factor can be factored out of the Hamiltonian after redefining the costate in terms of (loosely speaking) current "utils," rather than present-value-at-zero "utils." The only difference lies in the time interpretation of the costate.

Each player $i = 1, 2$ is initially endowed with a given amount of wealth:

$$x_i(0) = x_{i0} \tag{4.3}$$

The initial endowments of wealth need not be equal for both players. In fact, as it will be established below, the difference in the initial endowments of wealth between the players, is a key parameter in the model.

Using existing wealth as the sole input, at each point in time, each player can produce new wealth according to the following production function:

$$y_i(t) = y[x_i(t)] \tag{4.4}$$

where $y'(x) > 0$ and $y''(x) < 0$. In words, the production function is assumed to be a continuous, smooth, increasing, and strictly concave function of the stock of existing wealth. The stock of existing wealth is used as the input of the production function at each $t \in [0, T]$. It is assumed that all outlays of wealth for current consumption and other current actions are deductions from the flow of wealth produced at that point in time.

Besides using output to consume and/or produce for the next instant, each player may engage in *appropriation* actions, namely instantaneous outlays of wealth made to protect her existing wealth and/or grab the other player's existing wealth. It is also assumed that, at each point in time $t \in [0, T]$, under existing technology, only a fixed fraction $0 < \delta < 1$ of each player's existing stock of wealth is effectively subject to appropriation. In other words, the current (instantaneous) flows of production, consumption, or appropriation outlays are not subject to appropriation.

Appropriation actions are denoted by $a_i(t)$ and assumed to be nonnegative.[11]

[11] From this point on, the time reference in parenthesis is omitted to streamline the notation.

At $t \in [0, T]$, the fraction of her own wealth player i retains (the *retention rate*) is:

$$p_i = \frac{1}{1 + \theta a_j} \tag{4.5}$$

for $i \neq j = 1, 2$, where $\theta > 1$ is a constant parameter that reflects the efficacy of appropriation actions. Clearly, $0 \leq p_i \leq 1$. More specifically, $\lim_{a_j \to 0} p_i = 1$ and $\lim_{a_j \to \infty} p_i = 0$. Also, p_i is a monotonically decreasing function of a_j: $dp_i/da_j = -\theta/(1 + \theta a_j)^2 < 0$.

The portion of the other player's wealth a given player can effectively grab is:

$$\gamma(1 - p_j) = \gamma\Big(\frac{\theta a_i}{1 + \theta a_i}\Big) \tag{4.6}$$

for $i \neq \ j = 1, 2$, where $0 < \gamma < 1$ is a constant parameter (the *salvage ratio*) that captures the portion of wealth lost to appropriation by one of the players that is actually appropriated by the aggressor. In other words, only a fraction γ of the portion of wealth that player j loses is effectively appropriated by player i. Somehow the fraction $(1 - \gamma)$ winds up as a deadweight loss in the process. It follows from the result about p_i that $(1 - p_j)$ is a monotonically increasing function of a_i.

The instantaneous rate of change of player i's stock of wealth is given by:

$$\dot{x}_i = y(x_i) - c_i - a_i - \delta x_i + \delta x_i\Big(\frac{1}{1 + \theta a_j}\Big) + \gamma \delta x_j\Big(\frac{\theta a_i}{1 + \theta a_i}\Big) \tag{4.7}$$

where $\dot{x} \equiv dx/dt$. This is called the *equation of motion* of player i's wealth. In words, the rate of change of a player's wealth equals the output of current production, current consumption, and appropriation outlays, minus the portion of wealth subject to appropriation, plus the portion of one's own wealth retained and the portion of the other player's wealth appropriated.

The equation of motion can be expressed in terms of the retention rates and simplified further:

$$\dot{x}_i = y(x_i) - c_i - a_i - \delta x_i(1 - p_j) + \gamma\delta x_j(1 - p_i) \tag{4.8}$$

This being a one-good economy, the exchange of the good at each $t \in [0, T]$ would be pointless. On the other hand, the value of each unit of wealth transferred to the next instant may mean different amounts of "utils" to each player. In other words, the instantaneous shadow price of each player's wealth may differ. With intertemporal exchange allowed between the players (i.e. borrowing and lending), the two players could in principle trade the good intertemporally up to the point where the instantaneous shadow prices of wealth are equalized.

However, to simplify matters and focus strictly on appropriation, this model does not allow intertemporal exchange between the players. To frame this assumption differently, any discrepancy between the instantaneous shadow price of player i's wealth and player j's wealth can only translate into appropriation actions between them.

Each player's dynamic problem is to choose a strategy (i.e. a set of time paths for her controls over the life of the game $\{c_i^*(t), a_i^*(t)\}_0^T$ that maximizes her payoff functional, subject to her own wealth equation of motion, boundary conditions, nonnegativity constraints, and the strategy chosen by the other player.[12] Player i's individually-optimal strategy is a function of both players' existing stock of wealth.[13]

The transversality condition is given by:

$$x_i(T)\lambda_i(T) = 0 \tag{4.9}$$

[12]The states and controls are assumed to be nonnegative.

[13]In other words, this is a perfect-information differential game. Strategies that depend only on the current state of the system are known as *closed-loop* controls or Markovian strategies.

for at least one of the players $i = 1, 2$, where T is given exogenously or is to be determined endogenously. In words, the transversality condition says that the game ends when either the wealth of (at least one of) the players or its instantaneous shadow price is zero. The case of a given terminal time requires that the terminal instantaneous shadow price of wealth be pushed down to zero, since wealth has no use after T. If one player loses all her wealth, the game turns into a regular Ramsey-type optimal control problem for the surviving player.

4.2.2 The first-order conditions

It is assumed that the players have no prior binding agreement to cooperate, i.e. each of them acts independently of the other to maximize her individual payoff functional (4.1).

Player i's full Hamiltonian function for each $t \in [0, T]$ is:

$$\begin{aligned} H_i = u(c_i) + \lambda_{ii}\Big[y(x_i) - c_i - a_i - \delta x_i\Big(\frac{\theta a_j}{1+\theta a_j}\Big) + \gamma\delta x_j\Big(\frac{\theta a_i}{1+\theta a_i}\Big)\Big] \\ +\lambda_{ij}\Big[y(x_j) - c_j - a_j - \delta x_j\Big(\frac{\theta a_i}{1+\theta a_i}\Big) + \gamma\delta x_i\Big(\frac{\theta a_j}{1+\theta a_j}\Big)\Big] \end{aligned} \tag{4.10}$$

Unlike a regular optimal control problem, in the differential-game framework, two costates can be specified for player i. One of them, λ_{ii} captures the marginal effect on the objective functional of relaxing i's own equation of motion by one unit of wealth. It is the instantaneous shadow price or gross return rate of a unit of the player's own wealth transferred to the next instant, expressed in utility units of the current instant. More simply, λ_{ii} is called the *own* instantaneous shadow price. The second costate variable, λ_{ij}, captures the marginal effect on i's objective functional that results from a unit change in player j's wealth dynamic constraint. It is called here the *cross* instantaneous shadow price.

The first-order necessary conditions for an optimal consumption and appropriation strategy for player i at each $t \in [0, T]$, holding constant the strategy chosen by player j,[14] are the same conditions required to maximize i's Hamiltonian (4.10):

$$u'(c_i) = \lambda_i \tag{4.11}$$

$$\lambda_i - \lambda_i \gamma \delta x_j \Big[\frac{\theta}{1+\theta a_i} - \frac{\theta^2 a_i}{(1+\theta a_i)^2}\Big] = \lambda_j \delta x_j \Big[\frac{\theta}{1+\theta a_i} - \frac{\theta^2 a_i}{(1+\theta a_i)^2}\Big] \tag{4.12}$$

at $t \in [0, T]$ and for $i \neq j = 1, 2$. The detailed derivation of these conditions is shown in Appendix 4.

Note that, since x_i affects H_i and H_j in the same way, through the equations of motion of x_i and x_j, then $-\partial H_i/\partial x_i = -\partial H_j/\partial x_i = \dot{\lambda}_{ii} = \dot{\lambda}_{ji} = \dot{\lambda}_i$. Also, $-\partial H_j/\partial x_j = -\partial H_i/\partial x_j = \dot{\lambda}_{jj} = \dot{\lambda}_{ij} = \dot{\lambda}_j$. Therefore, $\lambda_{ii} = \lambda_{ji} = \lambda_i$ and $\lambda_{jj} = \lambda_{ij} = \lambda_j$ by construction of the Hamiltonians and the transversality condition.

The second-order sufficient conditions for a maximal value of the Hamiltonian and, thereby, of player i's payoff functional at each point in time are satisfied by the strict concavity of the felicity function and of the equation of motion in both c_i and a_i, since – assuming the instantaneous price of wealth is nonnegative – a linear combination of two concave functions is itself a concave function.

4.2.3 The Markovian Nash equilibrium

A *Markovian Nash equilibrium* reconciles the first-order conditions for both players at each $t \in [0, T]$. A Markovian Nash equilibrium is defined as the optimal consumption and appropriation strategy of a player under the assumption that the other player also chooses her own optimal strategy. If a Markovian Nash equilibrium exists and the players are at such an equilibrium, then they have no incentive to move away from it for a given set of parameters and boundary conditions.

The Markovian Nash equilibrium can be found by simultaneously solving the system of equations formed by the first-order conditions of both players, for the

[14] Technically, the strategy chosen by player j is restricted to a set of feasible strategies. In this model, the feasibility of a player's strategy is given by its nonnegativity, given the nonnegativity of the state variables.

control variables (current consumption c and appropriation outlays a), in terms of the parameters δ, θ, γ, the stocks of wealth of the players x_i, x_j, and the respective instantaneous shadow prices λ_i, λ_j.

By Pontryagin's maximum principle in the context of a differential game, the solution to the game's dynamic allocation – i.e. the optimal time paths for the stocks of wealth of both players and for their respective instantaneous shadow prices – must satisfy the Markovian Nash equilibrium at each $t \in [0, T]$.

The general Markovian Nash equilibria of the game is given by:

$$c_i^* = u'^{-1}(\lambda_i) \tag{4.13}$$

$$a_i^* = \frac{\sqrt{\theta \delta x_j \varrho_i} - 1}{\theta} \tag{4.14}$$

for $i \neq j = 1, 2$ and for each $t \in [0, T]$, where $u'^{-1}(.)$ indicates the implicit inverse of the marginal utility function (assuming it exists), the $\pm$ sign preceding the square-root operator is eliminated by using the nonnegativity conditions imposed by assumption on the control and state variables, $\varrho \equiv (\gamma \lambda_i - \lambda_j)/\lambda_i$ is the *switch* ratio, and the asterisk denotes point-in-time optimality. The detailed derivation of the Markovian Nash equilibria equations is shown in Appendix 4.

4.3 Analysis

This section analyzes the Markovian Nash results derived in the previous section. Subsection 4.3.1 interprets the condition for the optimal consumption path. Subsection 4.3.2 sorts out the conditions for a nonaggressive versus an aggressive equilibrium. Some of the qualitative dynamics of the game are examined in subsection 4.3.3. Subsection 4.3.4 refers the well-known single-agent optimal-control case.

4.3.1 Optimal consumption

To examine the implications of the first-order conditions and the Markovian Nash equilibrium (which satisfies them for both players simultaneously), consider the *elasticity of substitution* between consumption at two discrete points in time, t and s:

$$\sigma[c_t] \equiv -\frac{u'(c_s)/u'(c_t)}{c_s/c_t}\frac{d(c_s/c_t)}{d\{u'(c_s)/u'(c_t)\}}$$

The well-known result that the limit of this elasticity as the difference between s and t becomes arbitrarily small yields

$$\sigma[c(t)] = -\frac{1}{c(t)}\left(\frac{u'[c(t)]}{u''[c(t)]}\right)$$

is shown in Appendix 4. This expression says that the point or *instantaneous* elasticity of substitution, which turns out to be the reciprocal of the negative of the *elasticity of the marginal utility*, $\epsilon(c) \equiv [u''(c)c]/u'(c)$, is a measure of the curvature of the felicity function. Thus, the following expressions for the growth rate of consumption $\hat{c} \equiv \dot{c}/c$ can be derived substituting into condition (4.11):

$$\hat{c^*}_i = -\frac{1}{\epsilon}\hat{\lambda}_i = \sigma(c_i^*)\hat{\lambda}_i \tag{4.15}$$

Note that $\sigma(c_i) \geq 0$, because felicity is increasing in c_i and strictly concave, i.e. $\epsilon \leq 0$. Hence, in this form, condition (4.11) says that the relation between the growth rate of consumption and the growth rate of the instantaneous shadow price of wealth is nonnegative in a proportion determined by the instantaneous elasticity of substitution between consumption now and consumption in the next instant. This is a well-known result in the modern theory of economic growth.

In terms of the elasticity of marginal utility, condition (4.11) says that if felicity is more rather than less curved (i.e. if growing consumption yields a rapidly declining marginal utility) and consumption is strictly positive, then a player's growth rate of consumption will lag behind the growth rate of the instantaneous shadow price of her own wealth.

4.3.2 Distributional conflict

On the other hand, using the retention rate p defined above, condition (4.12) simplifies nicely to:

$$\frac{a_i^*}{p_i^* - (p_i^*)^2} = \delta \varrho_i x_j \tag{4.16}$$

To derive the parametric conditions under which $a_i \geq 0$, L'Hôpital's rule can be used to take the limit of this expression as a_i approaches zero from the right:

$$\lim_{a_i^* \to 0^+} \left(\frac{a_i^*}{p_i^* - (p_i^*)^2} \right) = \frac{1}{\theta} \tag{4.17}$$

Solving equation (4.16) valued at the limit for ϱ_i or, directly, from equilibrium condition (4.14), the following inequality must hold for $a_i \geq 0$:

$$\varrho_i \geq \frac{1}{\theta \delta x_j} \tag{4.18}$$

The detailed derivation of these results is shown in Appendix 4.

Inequality (4.18) words, player i's optimal appropriation actions at a given $t \in [0, T]$ will be positive if the player's switch ratio ϱ_i exceeds $1/(\theta \delta x_j)$.

Inequality (4.18) also implies that, if player i's appropriation outlays are positive, they will increase if, holding other things constant, (1) the difference between player i's instantaneous shadow price of own wealth and instantaneous shadow price of cross wealth, (2) the salvage ratio, (3) the efficacy of appropriation, or (4) the fraction of j's wealth subject to appropriation increase above a certain point.[15]

[15] More generally, it is the *value* of player j's wealth, $(x_j \lambda_j)$, that is a positively related to player i's appropriation actions. Along the optimal path of the economy, a player's shadow price cannot be held constant while her wealth varies, because a solution to her dynamic problem entails a definite relationship between her wealth and her shadow price.

The incentives for the players to resort to aggression come in the form of relatively large differences between the shadow prices of their respective wealths scaled by γ, θ, δ, and the amount of wealth possessed by the victim.

While it is the difference between the own shadow price (scaled by γ) and the cross shadow price that determines the *algebraic sign* of ϱ_i and, thereby, the algebraic sign of the argument in the square root operator of equilibrium condition (4.14), the specific values of θ and δ reduce or magnify the impact of this difference on the level of the appropriation outlays. To put it in other words, holding everything else constant, if positive, player i's appropriation actions will be greater the smaller the shadow price of her own wealth, the larger the *value* of wealth of her rival, the greater the salvage ratio, the more "productive" her appropriation actions, or the larger the portion of the players' wealth subject to appropriation.

In the context of this model, parameters δ, θ, and γ can be viewed as reflecting exogenous technological conditions. On the other hand, given the salvage ratio γ, the switch ratio ϱ_i is driven endogenously by the dynamics of the instantaneous shadow prices. This raises the question of what characterizes such dynamics.

4.3.3 The game's dynamics

To examine qualitatively the dynamics of the game, consider the Euler equation for player i:[16]

$$\dot{\lambda}_i = \lambda_i\Big[\delta\Big(\frac{\theta a_j^*}{1+\theta a_j^*}\Big) - y'(x_i)\Big] - \lambda_j\delta\gamma\Big(\frac{\theta a_j^*}{1+\theta a_j^*}\Big) \tag{4.19}$$

In terms of the retention rate, the growth rate of the instantaneous shadow price simplifies to:

$$\hat{\lambda}_i = \delta(1-p_j^*) - (\lambda_j/\lambda_i)\ \delta\gamma(1-p_j^*) - y'(x_i) \tag{4.20}$$

[16] The Euler equation of each player results from equalizing the time derivative of the instantaneous shadow price of player i's wealth and the negative of the partial derivative of the Hamiltonian with respect to the player's stock of wealth.

The Euler equation is known in the economic-growth literature as the Keynes-Ramsey rule.[17] In the context of this game, equation (4.19) or (4.20) could be called the *modified* Keynes-Ramsey rule and be interpreted as saying that the marginal rate of substitution between consumption now and consumption at the next instant must equal the marginal rate of transformation of wealth now into wealth at the next instant via production and/or appropriation. In the case of production, the marginal output is valued at the player's own instantaneous shadow price. In the case of appropriation, the retained output of appropriation is valued at the player's own instantaneous shadow price, but the grabbed output of appropriation is valued at the cross instantaneous shadow price.

Substituting equation (4.20) into condition (4.15) above, the optimal growth rate of player i's consumption can be expressed in terms of δ, θ, γ, p_j, her own marginal product $y'(x_i)$, and the ratio of cross to own instantaneous shadow prices of wealth:

$$\hat{c}_i^* = \sigma(c_i^*)\Big\{\delta(1-p_j^*)\Big[\frac{\lambda_i - \gamma\lambda_j}{\lambda_i}\Big] - y'(x_i)\Big\} \tag{4.21}$$

Or, in terms of the switch ratio:

$$\hat{c}_i^* = \sigma(c_i^*)\{\delta\varrho_j(\lambda_j/\lambda_i)(p_j^* - 1) - y'(x_i)\} \tag{4.22}$$

Clearly, if player i chooses to reduce one small portion of her wealth dc_i now and transfer it via production or appropriation in order to have more wealth for consumption at the next instant, the "utils" lost now will be $dc_i\ u'(c_i)$. On the other hand, the "utils" gained will be the sum of gains in "own utils' $dc_i\{[1 +$

[17] Blanchard and Fisher (1989).

$(y'(x_i) + \delta p_j]/[1+\delta]\}$ plus "cross utils" $dc_i[\delta\gamma(1-p_j)]$.[18] Along the optimal path, the "utils" lost and gained must be equal or else the path is not optimal.

Equation (4.21) also implies that the switch ratio is directly related to the dynamics of consumption and inversely related to the marginal product and the size of appropriation:

$$\frac{\lambda_i - \gamma\lambda_j}{\lambda_i} = \frac{\hat{c^*}_i/\sigma(c_i^*) - y'(x_i)}{\delta(1-p_j^*)} \tag{4.23}$$

If $a_i \to 0$, equation (20) and (21) turn into:

$$\hat{\lambda}_i|_{a_i\to 0} = -y'(x_i) \tag{4.24}$$

$$\hat{c}_i^*|_{a_i\to 0} = -\sigma(c_i^*)\ y'(x_i) \tag{4.25}$$

and equations (4.25), one per player, characterize entirely the dynamics of the optimal nonaggressive time path of the game's economy. In other words, the outcome of the game is the same as the outcome of the coordination or cooperative game.[19]

The canonical system of differential equations whose solutions are required to determine the optimal time paths of wealth for each player, as well as the optimal time paths of the shadow prices, is given by the equation of motion (4.7), Euler equation (4.19), given initial conditions $x_i(0) = x_{i0}$, and transversality condition (4.9) for both players $i = 1, 2$. Valued for the Markovian Nash equilibrium, the latter becomes:

$$x_i(T)u'[c_i^*(T)] = 0 \tag{4.26}$$

This condition says that, if the instantaneous value of the marginal utility at the terminal point T is positive, then it is not optimal for a player to keep a positive

[18] Remember that player i's instantaneous valuation of her own wealth coincides with player j's instantaneous valuation of i's wealth. So "cross utils" does not mean "utils" in the subjective sense of the other player only, but also own "utils" *as if* the one player had the same level of consumption as the other.

[19] See section 4.3.4.

stock of wealth at that point, since she could increase the value of her objective functional by consuming it.

The stationary states in the game, defined by $\dot{c}_i^* = \dot{a}_i^* = \dot{x}_i = 0$, must satisfy the following conditions:

$$\lambda_i y'(x_i) + \lambda_j \gamma\delta(1-p_j^*) = \lambda_i \delta(1-p_j^*) \tag{4.27}$$

$$\hat{\lambda}_i = \hat{\lambda}_j - \hat{x}_j\Big(\frac{\gamma\lambda_i - \lambda_j}{\lambda_j}\Big) \tag{4.28}$$

$$y(x_i) + \gamma\delta(1-p_i^*) = c_i^* + a_i^* + \delta x_i(1-p_j^*) \tag{4.29}$$

for each player $i = 1, 2$ over the life of the game $[0, T]$.

The first condition follows from equation (4.21), which in turn results from substituting the Euler equation (4.19) into first-order condition (4.11). The second condition for stationarity results from taking the time derivative of Markovian Nash solution (4.14) and setting it equal to zero. The third condition follows from the wealth equation of motion (4.7).

Substituting into the previous equations the optimal Markovian Nash control variables c_i^* and a_i^*, the canonical system can be expressed, exclusively in terms of the game parameters δ, θ, and γ, as a set of four relationships between the states x_i and the costates λ_i, two per player:

$$\begin{aligned} u'^{-1}(\lambda_i) = y(x_i) + \delta x_i\Big[\frac{\theta}{\sqrt{\delta\theta\varrho_j}} - 1\Big] + \frac{1}{\theta} \\ +\delta x_j \frac{\gamma\lambda_i[\sqrt{\delta\theta x_j \varrho_i} - 2] + \lambda_j}{\lambda_i\sqrt{\delta\theta x_j\varrho_i}} \end{aligned} \tag{4.30}$$

$$y'(x_i) = \delta\varrho_i + \frac{\lambda_j\sqrt{\delta\theta x_i \varrho_j}}{\theta x_i} \tag{4.31}$$

for $i = 1, 2$ and $t \in [0, T]$. In general, the time paths of the shadow prices is the dual reflection of the time paths of the players' stocks of wealth. However, neither the sign of the relationship between λ_i and x_i nor its monotonicity (or lack thereof) for the feasible set (given by $\{c_i^*, a_i^*\}_t > \mathbf{0}$) is apparent from the simple visual inspection of the canonical system.

In the Ramsey's model, the relationship between wealth and shadow price is monotonic.[20] If the same holds for this game, the switch ratio directly reflects the distribution of wealth between the players at each $t \in [0, T]$. In that case, for $t = 0$, the existence of positive appropriation outlays requires not only that the endowments of wealth be unequal $x_i > x_j$, but that the difference be sufficiently unequal for the dual reflection of this inequality to satisfy inequality (4.18).

In this game, except from their difference in the (given) initial endowments of wealth, the players are identical otherwise. The values of the parameters apply for both players. Felicity, the production function, and the appropriation function are all the same for both players, smooth and strictly concave. Also, each player's optimal appropriation actions depend only on the other player's stock of wealth at each $t \in [0, T]$.

It is possible that, in the dynamic solution of the game, the switch ratio $\varrho \equiv (\gamma\lambda_i - \lambda_j)/\lambda_i$, the decisive factor that tips the economy from its nonaggressive equilibrium into outright distributional conflict, reflects not only a difference between the players in their respective instantaneous shadow prices, but also the inequality in their levels of current consumption and in their stocks of wealth. In other words, that the switch ratio is a direct measure of the wealth inequality prevailing in the economy.

However, if the relationship between wealth and shadow price along a dynamic equilibrium is not monotonic, then the interpretation of the switch ratio is more problematic.

[20]The monotonicity (and negativity) of the relationship follows directly from equation (4.39) below.

Aside from the most trivial ("corner") stationary state of the game (i.e. $c_i^* = a_i^* = x_i^* = 0$, for at least one of the players), little can be said about other (interior) dynamic solutions of the game. Given the nonlinearity of the canonical system of differential equations of the game, computing specific numerical solutions, i.e. based on specific forms of the felicity and production functions and boundary conditions, may be required to examine in more detail the comparative dynamics of the game.

4.3.4 The coordination game

This section summarizes results that apply to the game if, before the game, the players strike a binding cooperative agreement whereby they eliminate appropriation outlays and share the game by coordinating their respective consumption rates. The following will consider this case. However, these same results apply to (1) the degenerate case of the differential game when the boundary conditions and relations between the parameters do not ensure the strict inequality case in (4.18), i.e. when $a_i = 0$, and to (2) any of the players individually, if the other player's stock of wealth or its own shadow price approach zero.

The economy's state and control variables are:

$$x = \pi x_1 + (1 - \pi)x_2 \tag{4.32}$$

$$c = \pi c_1 + (1 - \pi)c_2 \tag{4.33}$$

$$a = \pi a_1 + (1 - \pi)a_2 \tag{4.34}$$

where π is the agreed-upon weight of player i in the economy, assumed constant across the welfare function, the distribution of wealth, and the division of actions.

Assuming a simple additive welfare function, both players coordinate the choice of their control trajectories to maximize the joint objective functional:

$$W = \int_0^T u[c(t)]dt \tag{4.35}$$

for $t \in [0, T]$, subject to the boundary conditions, the nonnegativity constraints, and the following equation of motion:

$$\dot{x} = y(x) - c \tag{4.36}$$

For the players, maximizing equation (4.35) is equivalent to maximizing the Hamiltonian:

$$H = u(c) + \lambda[y(x) - c] \tag{4.37}$$

at each $t \in [0, T]$, since δ and a_i for $i = 1, 2$ are zero by agreement.

This is a streamlined version of Ramsey's (1928) model of growth, which has been studied extensively.[21] For reference purposes, the first-order condition for a maximum value of the functional at each point in time is:

$$u'(c) = \lambda \tag{4.38}$$

The time path of the aggregated stock of wealth in the economy is given by the equation of motion and the time path of the instantaneous shadow price of wealth is given by:

$$\dot{\lambda} = -\lambda y'(x) \tag{4.39}$$

By Pontryagin's maximum principle, the optimal paths of consumption and wealth $\{c^*(t), x^*(t)\}_0^T$ must satisfy the system of differential equations formed by (4.36) and (4.39) valued at the first-order condition. Given a boundary condition on initial wealth $x(0) = x_0$ and on the terminal instantaneous shadow price of wealth $\lambda(T) = 0$, the system can be solved for the optimal paths of wealth and its shadow price.

[21] The extra simplifying assumptions adopted in this paper (zero depreciation and zero population growth) lead to a golden rule level of production that is at once the optimal and the maximal rates of consumption.

Perhaps a more intuitive description of the dynamics of the system can be attained by taking the time derivative of the costate in the point-in-time first-order condition, substituting in the state and costate differential equations, and using the instantaneous elasticity of substitution $\sigma(c) \equiv -u'/(u''c)$, so that the system of differential equations becomes:

$$\dot{c} = \sigma(c)\ c\ y'(x) \tag{4.40}$$

$$\dot{x} = y(x) - c \tag{4.41}$$

Thus, the dynamics of consumption and wealth accumulation in this economy can be summarized by contrast to the steady or stationary state where $\hat{c} = \hat{x} = 0$ (in which the levels of consumption $\bar{c}$ and wealth stock $\bar{x}$ are constant over time) and summarized as follows:

$$\hat{c} > 0 \text{ if } y'(x) > 0 \text{ i.e. if } x < \bar{x} \tag{4.42}$$

$$\hat{c} < 0 \text{ if } y'(x) < 0 \text{ i.e. if } x > \bar{x} \tag{4.43}$$

$$\hat{c} = 0 \text{ if } y'(x) = 0 \text{ i.e. if } x = \bar{x} \tag{4.44}$$

$$\hat{x} > 0 \text{ if } y(x) > c \tag{4.45}$$

$$\hat{x} < 0 \text{ if } y(x) < c \tag{4.46}$$

$$\hat{x} = 0 \text{ if } y(x) = c \tag{4.47}$$

4.4 Literature

This section discusses narrow slivers of literature relevant to the model in this paper. Subsection 4.4.1 refers to some predecessors of the model in this paper. Subsection 4.4.2 summarizes the empirical research that motivated the model. Subsection 4.4.3 closes the section with references and thoughts on the notion of cooperation between self-interested economic agents.

4.4.1 Theoretical references

The key theoretical predecessor for this paper is Grossman and Kim's (1995) pioneering two-player static game. The model in this paper owes to Grossman and Kim the specification of the appropriation function as a hyperbolic function. However, this paper modifies the set-up of the appropriation function in a crucial respect: it abandons the distinction between defensive and offensive actions.

The decision to alter Grossman and Kim's specification of the appropriation function can be justified on two grounds. First, not much is lost by shedding the distinction. Arguably, the key element in the specification is the smooth concavity of the appropriation function. The second reason is tractability. With defense specified as a type of action separate from attack, the first-order necessary condition for an individual optimum that determines the optimal level of appropriation actions (defense and attack) become dependent on the player's own wealth, aside from depending on the other player's wealth. This turns the derivation of a Markovian Nash equilibrium into a combinatorial nightmare. On the other hand, without the distinction, the Markovian Nash conditions are easy to pin down.

Doubtlessly, the determination of the Markovian Nash equilibrium is the biggest analytical roadblock in solving differential game models and deriving clear economic insight from them. This is perhaps the main reason why this method has so far attracted little interest among economic theorists. This is remarkable, since early theoretical results and applications of differential game theory date back to the mid 1950s and early 1960s. Isaacs (1965) compiles the seminal papers. Friedman (1971) provides a systematic and general description of the mathematics of differential games, including the theorem of the existence of a Markovian Nash equilibrium (at the time referred as "the saddle point solution"). Intriligator (1971) introduces differential games to students of economics. Dockner et al. (2000) has a modern version of the existence theorem.

Simpler (more tractable) forms of specifying the appropriation function seem much less interesting or have been tried by other authors. Lancaster (1973) and Hoel (1978) use the differential game approach to highlight what Lancaster calls the "dynamic inefficiency of capitalism." Their specification allows them to obtain elegant and straightforward "bang-bang" solutions to their models. They achieve simplicity by ruling out extra-economic appropriation – and the nonlinearities that arise from its specification. They postulate "workers" and "capitalists" as players engaged in regular exchange in the labor and product markets. Since their definition of "capitalism" is such that capitalists own all the physical wealth and the workers only their labor power, Lancaster's and Hoel's papers are similar to mine insofar as they all show that a dynamic welfare loss ultimately results from inequality. The difference is that, in their models, the inequality between workers and capitalists translates not into appropriation, but into a separation between the current consumption (and thereby saving) and investment decisions *à la* Keynes.

To judge by the topical literature, engineering and operations research specialists are rather comfortable with numerical approximate solutions to *both* the Markovian Nash equilibria and the solution to the dynamic allocation problem.[22] The theoretical economic literature is far from having adopted this attitude. Instead, it usually expects sharp analytical solutions and qualitative and – even – quantitative predictions that can be demonstrably reconciled with the tested tenets of basic economic intuition. While there is some acceptance of numerical solutions to the dynamic allocation problem proper, the suspicion remains. The concern seems

[22] For a rare paper using numerical approximation to compute both the Markovian Nash equilibrium and the dynamic solution to an economic differential game, see Itaya (2000).

to be that – given the complexity of the relations involved – the numerical approximation of a Markovian Nash equilibrium, when fed into the derivation of the dynamic allocation solution, could limit or even distort the outcome to the point of rendering it useless.

4.4.2 The empirical debate on inequality and growth

Galor and Zeira (1993) are credited with reviving interest in the causal mechanism between initial inequality and subsequent growth. The empirical finding that larger initial income inequality is associated with lower subsequent growth is due to Person and Tabellini (1994) and Alesina and Rodrik (1994). Bénabou (1996) and Perotti (1996) surveyed the empirical literature and reported that most studies found the same result.

Forbes (2000) challenged this finding and, using a new data panel developed by Deininger and Squire (1996), reported instead a positive relation between initial income inequality and subsequent growth. Li and Zou (1998) also claimed to have found a positive relation. Deininger and Squire (1998) themselves conducted an analysis of their data set and found that the negative relation was robust. Székely and Hilgert (1999) questioned the quality of the Deininger and Squire data for Latin America and showed that Forbes' results might have been dependent upon the method used to compute inequality. Birdsall and Londono (1997) found a negative relation between initial human-capital inequality and subsequent growth.

Barro (1999), analyzing an extended data set, found "little overall relation between income inequality and rates of growth and investment." However, "higher inequality tends to retard growth in poor countries and encourage growth in richer places." Since most countries in the world are classified as poor and most people in the world live in poor countries, it is apparent that the former conclusion has a larger relevance in global welfare than the latter. Lucas (1988) has suggested compellingly that there are massive gains in efficiency to be made in the world economy by helping poor and large economies to grow.[23]

Sokoloff and Engerman (2000) and Engerman and Sokoloff (2002) marshalled a large body of historiographic information to draw a contrast between Latin America and Anglo America, where the former started off with a more skewed distribution of its factor endowments, which in turn led it to evolve weaker legal and political institutions and, through them, experience a poorer economic performance. Easterly (2001a) and Easterly (2001b) used a careful econometric specification to validate Engerman and Sokoloff's hypothesis. While the challenge by Forbes (2000) and Li and Zou (1998) was based on panel regressions, Panizza (2002) analyzed a cross-state data panel for the United States. He found no evidence of a positive relation and "some evidence" of a negative relation, although sensitive to the method used to measure inequality.[24]

4.4.3 Random thoughts on cooperation

It is common in the general equilibrium literature to contrast the decentralized markets result to that derived without appeal to separation theorems, i.e. by invoking the existence of some sort of "social planner." In the welfare analysis of general equilibrium, the social planner results are used as the baseline to compare the results obtained for the decentralized markets case. Implicit in the exercise is

[23] "Is there some action a government of India could take that would lead the Indian economy to grow like Indonesia's or Egypt's? If so, *what*, exactly? If not, what is it about the 'nature of India' that makes it so? The consequences for human welfare involved in questions like these are simply staggering: Once one starts to think about them, it is hard to think about anything else." Lucas (1988).

[24] The initial inequality considered in the empirical literature refers to consumption, income, and ownership of an array of assets, physical, human, and even intangibles. Some studies include markers such as race, ethnicity, language, gender, or age, where such markers lead to social ranking. The conceptual and empirical relations among physical wealth, human wealth, income, and consumption are reasonably well established. In this paper, we refer to 'wealth inequality' in the broadest sense.

the notion that an economy in which all self-interested economic agents perfectly coordinate their individual actions is superior to any conceivable alternative.[25] More realistic economic arrangements (e.g. decentralized markets) can only aspire to match the welfare heights that such a perfect economy would attain if it could only come about.

In spite of the highly abstract – in fact, heroic – character of the assumptions underpinning general equilibrium (perfect information, perfect markets, convexity of preferences and technology, and zero externalities), the decentralized markets case appears as much more realistic, more robust, and more likely to emerge out of actual historical economic evolution than perfect coordination as personified in the abstract role of the "social planner." After all, the chief role of the social planner, i.e. to provide a "consistent" (not self-contradictory) mapping from individual utility to the welfare function, is left completely unexplained.

Arrow (1963) looked carefully into this mapping from individual utility functions to a general welfare function and derived very stringent conditions for such a mapping to exist and for the resulting welfare function to meet some basic "rationality" criteria. One of the conditions is, precisely, the existence of a "dictator" able to form a consistent welfare function, thus getting around the "impossibility" of interpersonal utility comparisons. The "social planner" can thus be viewed as a sort of "benevolent dictator."

Arrow's Impossibility Theorem notwithstanding, welfare and economic policy analysis continue to depend on the notion of social welfare. Considering how pervasive redistributive actions (e.g., fiscal policy) are, in virtually every economy, it is clear that the criterion of Pareto efficiency, by eluding distributive judgments,

[25] For an example of this practice, see Stokey and Lucas (1989), chapter 1.

is too restrictive to be of practical use in welfare economics and policy analysis. In most cases, policymakers face re-distributive tradeoffs associated with different economic policy choices. It is rarely the case that there is a clearly Pareto-superior choice.[26] It is no surprise then that, in the absence of uncontroversial results (similar to Pareto efficiency) to guide welfare economists and policymakers in redistributive dilemmas, theorists are forced to forge more restrictive welfare notions and even flirt with the old cardinalism.[27]

Other strands of the literature suggest how the idea of cooperation in the strategic interaction between economic agents may be an optimal response. For instance, one way to view the cooperative game is as the outcome of a merger of the two players' interests in order to internalize the external costs from their nonmarket-mediated interaction (i.e., appropriation). In our model, intertemporal exchange between the players is excluded by assumption. Therefore, a formal real interest rate does not emerge. However, this does not mean that prices are absent. The instantaneous *shadow prices* implicit in production and appropriation are in the nature of what Coase calls "prices in their widest sense." Thus, the negative externalities of appropriation can be viewed as large-scale Coasian transaction costs that might be better handled by a merger of the players' interests into a single economic entity. Examples of this are "firms":

> It is clear that an alternative form of economic organization which could achieve the same result at less cost than would be incurred by [bargaining between private owners] would enable the value of production to

[26]Stiglitz (2003) claims that facing gray-area situations with no evident Pareto-improving policies in sight is the rule in actual policymaking.

[27]On the former, see Bardhan, Bowles, and Gintis (1998), who replace the notion of "Pareto efficient," unable to judge the welfare effects of nonmarket-mediated asset redistribution, with that of "productivity enhancing," which denotes welfare gains from nonmarket-mediated asset redistribution, in situations where informational imperfections lead to incomplete or too-costly-to-enforce contracts. On the latter, see for instance Layard (2003).

> be raised. [...] [T]he firm represents such an alternative to organizing production through [...] transactions [between private parties]. Within the firm, individual bargains between the various co-operating factors of production are eliminated and for a [...] transaction [between private owners] is substituted an administrative decision. [...] In effect, [...] the firm would acquire the legal rights of all the parties, and the rearrangement of activities would not follow on a rearrangement of rights by contract but as a result of an administrative decision as to how the rights should be used." Coase (1960, pp. 115-116).

However, in this case as well, the precise mechanism by which the merger is designed and implemented remains exogenous.

Sen (1997) argues elegantly that a Pareto superior solution to the prisoner's dilemma game would be achieved by self-interested players if they behaved paradoxically, i.e., by turning it into an "assurance game" (under a principle of reciprocity, players give each other prior assurances that they will not shirk) or under the assumption of "socially conscious" play (each player prefers to do the right thing whether or not the other does the same):

> That the Prisoner's Dilemma could disappear if people had different preferences is true but hardly interesting. What is, however, quite significant is the fact that even if the people involved continued to have the same Prisoner's Dilemma type preferences, but behaved as if their preferences were as in the Assurance Game (or better still *as if* they had [...] "socially conscious" preferences [...]), they could be better off *even in terms of their true preferences.*[28]

[28]Sen (1997), pp. 98-99.

Sen's scenario is that of prisoner's dilemma games in which self-interested players remain self-interested in their felicity function while behaving *as if* it (their felicity function) were altruistic. This is a more sophisticated view than that of invoking the altruistic behavior of the players as a *deux ex machina*.[29] But, still, it requires, rather implausibly, that the set of preferences individuals use to subjectively map their actions to their wellbeing be different by assumption from the preferences that guide their actual behavior in the face of constraints.

Sen's reflections are a reply to Marx, whose description of "pure" communism is that of a "coordinated-game" type of society in which common ownership excludes formal exchange. Marx held the view that the emergence of a communist society was necessary because the "socialization of production" (and life in general) would increasingly require the "socialization of ownership." By the phrase "socialization of production," he meant an increasing interdependence between producers, mainly due to technological progress.[30] Marx seemed to have envisioned the emergence of a pure communist society, without formal exchange, as the result of a long transition that required the suppression of the main forms of economic inequality and the gradual development of a new ethics of cooperation and publicly-minded outlook.[31]

[29] There is a growing literature on the evolution of altruistic preferences and cooperation from first economic principles, partly spanned by Axelrod's (1984) work. For an example, see Bowles and Gintis (2000).

[30] "Let us imagine an association of free men, working with the means of production held in common, and expending their many different forms of labor-power in full self-awareness as one single social labor force." (1976, p. 171.) "Within the collective society based on common ownership of the means of production, the producers do not exchange their products; just as little does the labor employed on the products appear here as the value of these products, as a material quality possessed by them, since now, in contrast to capitalist society, individual labor no longer exists in an indirect fashion but directly as a component part of total labor." (1938, p. 85.) "On the basis of communal production, the determination of time remains, of course, essential. The less time the society requires to produce wheat, cattle, etc., the more time it wins for other production, material or mental. Just as in the case of an individual, the multiplicity of its development, its enjoyment and its activity depends on the economization of time. Economy of time, to this all economy ultimately reduces itself. Society likewise has to distribute its time in a purposeful way, in order to achieve a production adequate to its overall needs; just as the individual has to distribute his time correctly in order to satisfy the various demands on his activity. Thus, economy of time, along with the planned distribution of labor time among the various branches of production, remains the first economic law on the basis of communal production. It becomes law, there, to an even higher degree. (1973, p. 172-173.)

[31] A brief discussion of the transitional process leading to pure communism is in Marx (1938). Sen (1995) provides an erudite and meticulous discussion of the difficulties of the notion of economic and/or social equality.

In modern terms, Marx envisioned technological progress as a process leading to the emergence of ever larger and more pervasive externalities that markets, based on private ownership, would be unable to handle efficiently. The agency for the transition to communism would be the "propertyless direct producers," the workers, who would have the least vested interest in the *status quo*.[32] However, the specifics of this transitional process are missing in Marx's writings or vaguely described as a process of workers' collective self-growth through their struggle against the capitalists. It is not clear the extent to which Marx understood the major sources of moral hazard arising from the common disposition of productive wealth, let alone how to deal with them in practice.[33]

Keeping in mind that the notion of cooperation used in this paper does not distinguish explicitly between direct cooperation and cooperation mediated by exchange in markets,[34] a loose interpretation of the implications of the model above is that – at least when considering a given point in time – the conditions that enable self-interested players to cooperate may be much more robust that usually thought. Again, at least for a given point in time, distributional conflict appears to be the exception.

4.5 Conclusions

This paper presented a dynamic model of a two-agent economy with production and appropriation using the framework of differential games. The closed-form

[32]Another way to frame Marx's view of technological progress in modern terms is as a process by which an ever larger set of goods becomes *public*. A public good is both *nonrivalrous* (on the extreme, *nondepletable*) and *nonexcludable*. While the nonrivalrous (and nondepletable) character of goods depends on their physical or technical attributes, their excludability is socially conditioned. As suggested above, excludability is another name for the ability of individuals or their agencies to enforce their ownership rights and, in the terms of our model, is inversely related to the extent of appropriation.

[33]Private ownership can be viewed as a rough form of private insurance in the face of economic uncertainty. Similarly, public ownership can be viewed as social insurance aimed to eliminate unsystematic risk. For a modern treatment of the topic of social insurance, see Shiller (1996).

[34]In fact, free voluntary exchange through markets (as opposed to appropriation) could be viewed as an organized form of cooperation. On the other hand, direct voluntary cooperation, in which reciprocity is not regulated by prices or even enforced, can be viewed as an informal mode of exchange.

Markovian Nash equilibrium of this economy was determined and information about the economics of appropriation and growth was extracted from it.

Given initial conditions and parameter values, for a given point in time, the model requires strict conditions for appropriation outlays to be positive, essentially in the form of large differences between the instantaneous shadow prices of each player's wealth. While the time paths of the shadow prices in terms of the players' stocks of wealth at each point in time are not evident in the analysis, the difference between the shadow prices is the dual reflection of the differences between the stocks of wealth. If the relationship between each player's shadow price and her stock of wealth is monotonic, then the switch ratio is a one-to-one reflection of the wealth inequality prevailing in the economy at each point in time.

Without a full dynamic solution of the game, it is difficult to decide whether, as a result of the strict concavity of the appropriation function, the system has a self-correcting mechanism built in that prevents initial disparities from exploding to the point where one of the players losses all her wealth or, instead, the nonlinearities in the canonical system of differential equations, that the dynamic allocation optimal paths must satisfy, build up initial small disparities in wealth possession (and shadow prices) over time to the point of creating conditions that induce distributional conflict. If the stationary states of the game are stable, it seems clear that the introduction of randomness in the model would make it more likely to generate distributional conflict situations.

The full solution of the dynamical allocation problem of the game, and the analysis of its implications, is left for future work.

Appendices

Appendix 2

Table 2.2.1. Mexico: Selected economic indicators 1989-1998 (average annual percent change)

Item	1989-1993	1994-1998
Gross Domestic Product	3.8	3.0
Manufacturing GDP	4.3	5.5
Maquiladora gross value added[1]	7.0	14.0
Exports[2]	11.5	20.3
Manufacturing exports[2]	12.5	20.9
Maquiladora exports	20.4	19.4
Gross investment	7.6	12.0
Gross manufacturing investment	5.4	9.4
Foreign Direct Investment (FDI)	12.2	5.8
Industry division FDI[3] [4]	24.7	1.5
Manufacturing sector FDI[3]	n/a	6.4
Total employment	2.7	2.2
Manufacturing employment	1.8	2.8
Maquiladora employment	5.9	16.0

Source: Author's calculations based on data from INEGI, Sistema de Cuentas Nacionales, www.inegi.gob.mx.

[1] 1991-1994 and 1995-1998.

[2] 1991 skipped due to change in methodology that makes data not comparable.

[3] 1989-1993 and 1996-1998.

[4] The industry division is constituted by the manufacturing, construction, and gas & electricity sectors.

Table 2.2.2. Mexico: Selected economic indicators 1988, 1993, 1998 (%)

Item	1988	1993	1998
Manuf GDP/total GDP	18.6	19.0	21.3
Maquil value added/manuf GDP	4.8	5.2	7.6
Manuf exports/total exports	56.1	78.9	89.6
Maquil exports/manuf exports	20.3	53.2	50.3
Manuf paid labor force/total paid labor force	12.6	12.0	12.3
Maquil paid labor force/manuf paid labor force	13.8	15.9	26.9
Manuf gross investment*/total gross investment*	38.4	46.2	52.0
Industry sector FDI/total FDI	32.3	47.4	62.4
Manuf FDI/total FDI	n/a	n/a	59.8

Source: Author's calculations based on data from INEGI, Sistema de Cuentas Nacionales, www.inegi.gob.mx.

* Measured as fixed capital formation gross of depreciation.

Table 2.2.3. Mexico's Manufacturing: Total and foreign-owned plants 1988, 1993, 1998

Year	Total number of plants	Percent change (5-year) (%)	Foreign-owned plants	Percent change (5-year) (%)
1988	135,033		1,481	
1993	265,427	96.6	2,584	74.5
1998	344,118	29.6	2,832	9.6

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.

Table 2.2.4. Mexico's Manufacturing: Share of foreign owned plants by group 1988, 1993, 1998

	Shares			Percent change (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	0.21	0.22	0.19	4.8	-13.6
Textiles, apparel, leather	0.74	0.68	0.90	-8.1	32.4
Wood, wood products	0.30	0.26	0.15	-13.3	-42.3
Paper, paper prod, print, publish	0.99	0.75	0.44	-24.2	-41.3
Chemicals, oil prod, rubber, plastic	6.72	7.44	5.80	10.7	-22.0
Non-metal miner, except oil, coal prod	0.49	0.41	0.23	-16.3	-43.9
Basic metallic industries	4.19	8.39	5.88	100.2	-29.9
Metallic prod, machines, equipment	2.77	2.52	1.94	-9.0	-23.0
Other manufacturing industries	3.41	1.47	1.11	-56.9	-24.5
Total manufacturing	1.10	0.97	0.82	-11.8	-15.5

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.

Table 2.2.5. Mexico's Manufacturing: Gross value added per worker by group 1988, 1993, 1998

	Gross value added per worker[1]			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	24.31	47.10	40.78	93.7	-13.4
Textiles, apparel, leather	13.21	18.15	12.96	37.4	-28.6
Wood, wood products	9.03	16.36	13.90	81.2	-15.1
Paper, paper prod, print, publish	25.12	32.73	32.42	30.3	-1.0
Chemicals, oil prod, rubber, plastic	47.64	65.07	51.23	36.6	-21.3
Non-metal miner, except oil, coal prod	25.94	48.28	49.96	86.1	3.5
Basic metallic industries	41.30	59.81	n/a[2]	44.8	n/a[2]
Metallic prod, machines, equipment	26.62	29.62	32.15	11.3	8.5
Other manufacturing industries	12.33	22.58	17.36	83.1	-23.1
Total manufacturing	26.21	36.84	32.84	40.6	-10.8

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.

[1] Constant 1988 MXN.

[2] Outliers make this figure anomalous.

Table 2.2.6. Mexico's Manufacturing: Gross value added per unit of net fixed assets 1988, 1993, 1998

	Gross value added per unit of net fixed assets*			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	0.70	1.03	0.80	47.2	-22.6
Textiles, apparel, leather	0.72	0.97	0.78	34.1	-19.7
Wood, wood products	0.69	0.90	0.79	29.7	-11.8
Paper, paper prod, print, publish	0.59	0.52	0.47	-11.2	-10.6
Chemicals, oil prod, rubber, plastic	0.38	0.71	0.46	83.6	-34.6
Non-metal miner, except oil, coal prod	0.40	0.54	0.43	34.2	-20.7
Basic metallic industries	0.17	0.23	0.35	36.4	49.9
Metallic prod, machines, equipment	0.78	0.95	0.93	21.9	-2.2
Other manufacturing industries	0.82	1.31	1.13	58.6	-13.1
Total manufacturing	0.50	0.76	0.64	52.2	-15.8

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.
* Constant 1988 MXN.

Table 2.2.7. Mexico's Manufacturing: Gross value added per unit of intermediate inputs 1988, 1993, 1998

	Gross value added per unit of intermediate inputs*			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	0.48	0.69	0.57	44.2	-18.4
Textiles, apparel, leather	0.59	0.77	0.66	29.5	-14.2
Wood, wood products	0.57	0.70	0.66	29.5	-14.2
Paper, paper prod, print, publish	0.54	0.70	0.66	28.6	-5.0
Chemicals, oil prod, rubber, plastic	0.50	0.61	0.44	22.0	-28.2
Non-metal miner, except oil, coal prod	0.80	1.06	0.99	31.3	-5.9
Basic metallic industries	0.41	0.28	0.42	-30.0	48.5
Metallic prod, machines, equipment	0.68	0.62	0.56	-8.7	-9.8
Other manufacturing industries	0.79	1.06	0.93	34.4	-12.0
Total manufacturing	0.55	0.64	0.55	16.3	-14.5

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.
* Constant 1988 MXN.

Table 2.2.8. Mexico's Manufacturing: Net fixed assets per worker 1988, 1993, 1998

	Net fixed assets per worker*			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	34.70	45.66	51.07	31.6	11.8
Textiles, apparel, leather	18.29	18.74	16.65	2.5	-11.1
Wood, wood products	13.06	18.25	17.58	39.7	-3.7
Paper, paper prod, print, publish	42.68	62.64	69.40	46.8	10.8
Chemicals, oil prod, rubber, plastic	123.94	92.20	111.04	-25.6	20.4
Non-metal miner, except oil, coal prod	64.29	89.17	116.40	38.7	30.5
Basic metallic industries	241.27	256.14	396.82	6.2	54.9
Metallic prod, machines, equipment	34.06	31.09	34.50	-8.7	11.0
Other manufacturing industries	14.98	17.30	15.30	15.5	-11.6
Total manufacturing	52.55	48.54	51.38	-7.6	5.8

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.
* Constant 1988 MXN.

Table 2.2.9. Mexico's Manufacturing: White- to blue-collar workers' ratio 1988, 1993, 1998

	White- to blue-collar workers' ratio			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	0.38	0.40	0.41	4.5	1.8
Textiles, apparel, leather	0.21	0.20	0.14	-4.2	-27.2
Wood, wood products	0.17	0.17	0.15	-3.1	-8.0
Paper, paper prod, print, publish	0.51	0.59	0.50	16.4	-15.4
Chemicals, oil prod, rubber, plastic	0.45	0.44	0.38	-1.5	-14.6
Non-metal miner, except oil, coal prod	0.28	0.26	0.23	-4.9	-12.5
Basic metallic industries	0.37	0.35	0.40	-6.5	14.1
Metallic prod, machines, equipment	0.32	0.28	0.21	-11.7	-24.6
Other manufacturing industries	0.29	0.28	0.19	-2.4	-32.5
Total manufacturing	0.33	0.32	0.26	-3.1	-19.3

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.
* Constant 1988 MXN.

Table 2.2.10. Mexico's Manufacturing: Average plant size (workers per plant) 1988, 1993, 1998

	Workers per plant			Percent change (5-year) (%)	
Industry group	1988	1993	1998	1988-1993	1993-1998
Food, beverages, tobacco	10.9	6.2	5.4	-43.1	-12.9
Textiles, apparel, leather	26.3	11.0	14.8	-58.2	34.5
Wood, wood products	8.5	3.8	3.7	-55.3	-2.6
Paper, paper prod, print, publish	18.4	11.8	10.3	-55.3	-2.6
Chemicals, oil prod, rubber, plastic	82.7	52.8	44.0	-36.2	-16.7
Non-metal miner, except oil, coal prod	10.6	5.8	5.0	-45.3	-13.8
Basic metallic industries	139.8	188.2	146.5	34.6	-22.2
Metallic prod, machines, equipment	29.8	19.5	20.8	-34.6	6.7
Other manufacturing industries	24.6	7.9	8.2	-67.9	3.8
Total manufacturing	19.5	10.8	11.0	-44.6	1.9

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.

Table 2.2.11. Mexico's Manufacturing: Overall and foreign-owned Herfindahl-Hirschman index 1988, 1993, 1998

	H-H index			Percent change (5-year) (%)	
	1988	1993	1998	1988-1993	1993-1998
Manufacturing sector	0.279	0.247	0.263	-11.4	6.3
Foreign-owned group	0.310	0.291	0.311	-6.3	6.8

Source: Author's calculations based on data from INEGI, Censos Económicos 1989, 1994, 1999.

Table 2.5.1. Mexico's Manufacturing 1988, 1993, 1998: Foreign Ownership and TFP

	Without interactions		With interactions	
$\ln X$	OLS	SF	OLS	SF
$\ln L$	0.6535	0.6551	0.6466	0.6491
	(0.0105)***	(0.0104)***	(0.0114)***	(0.0114)***
$\ln K$	0.4332	0.4330	0.4458	0.4457
	(0.0069)***	(0.0068)***	(0.0077)***	(0.0076)***
F	0.5623	0.5684	4.0021	4.1320
	(0.0685)***	(0.0683)***	(0.9695)***	(0.9688)***
$F * t_1$ (1993)			0.3593	0.3831
			(0.1772)**	(0.1771)**
$F * t_1$ (1998)			1.2984	1.3256
			(0.1809)***	(0.1807)***
$F * \ln L$			-0.1083	-0.1248
			(0.0661)	(0.0659)*
$F * \ln K$			-0.3440	-0.3457
			(0.0430)***	(0.0423)***
t_1 (1993)	-0.9500	-0.9674	-0.9519	-0.9719
	(0.0258)***	(0.0261)***	(0.0278)***	(0.0279)***
t_1 (1998)	-1.4822	-1.4942	-1.5163	-1.5301
	(0.0256)***	(0.0258)***	(0.0275)***	(0.0276)***
$F * \ln N$			0.8095	0.7998
			(0.1019)***	(0.1003)***
$F * \ln W$			0.2395	0.2391
			(0.0937)**	(0.0926)***
$F * \ln H$			0.3081	0.2957
			(0.1277)**	(0.1257)**
A_0 (1988)	1.7230	2.2640	1.6339	2.1862
	(0.0647)***	(0.0745)***	(0.0665)***	(0.0750)***
$\ln N$	-0.1323	-0.1403	-0.1374	-0.1464
	(0.0075)***	(0.0075)***	(0.0076)***	(0.0076)***
$\ln W$	0.0791	0.0806	0.0700	0.0713
	(0.0097)***	(0.0097)***	(0.0101)***	(0.0100)***
$\ln H$	-0.0294	-0.0209	-0.0459	-0.0363
	(0.0156)*	(0.0156)	(0.0164)***	(0.0163)**
Industry group fixed effects[1]	Yes	Yes	Yes	Yes
State fixed effects[2]	Yes	Yes	Yes	Yes
F*Industry group interactions	No	No	Yes[1]	Yes[1]
F*State interactions	No	No	Yes[2]	Yes[2]
N	9217	9217	9217	9217
R^2	0.8822		0.8857	
Wald χ^2		69146.02		72153.18

Standard errors in parenthesis. * Significant at the $p = 0.01$ level. ** Significant at the $p = 0.05$ level. *** Significant at the $p = 0.1$ level. [1] See Table 2.5.2. [2] See Tables 2.5.3.

Table 2.5.2. Manufacturing industry group main fixed effects and interactions with foreign ownership
(Base values: "Food, beverages, tobacco" and "No foreign ownership")

	Without interactions		With interactions			
	Main effects		Main	Interact	Main	Interact
Industry group	OLS	SF	OLS		SF	
Textiles, apparel, leather	0.0468	0.0312	0.0662	-1.0660	0.0518	-1.1747
	(0.0260)*	(0.0259)	(0.0268)**	(0.3149)***	(0.0266)*	(0.3133)***
Wood, wood products	-0.2841	-0.2889	-0.2543	-1.4758	-0.2584	-1.5923
	(0.0333)***	(0.0330)***	(0.0338)***	(0.5508)***	(0.0334)***	(0.5473)***
Paper, paper products, printing, publishing	0.2190	0.2030	0.2603	-1.1314	0.2432	-1.1931
	(0.0351)***	(0.0349)***	(0.0362)***	(0.4989)**	(0.0359)***	(0.4966)**
Chemicals, oil products, rubber, plastic	0.3319	0.3179	0.2995	-0.6617	0.2881	-0.7710
	(0.0280)***	(0.0279)***	(0.0305)***	(0.2923)**	(0.0303)***	(0.2911)***
Non-metal minerals, except oil & coal prod	0.0361	0.0275	0.0470	-0.7559	0.0413	-0.9209
	(0.0297)	(0.0295)	(0.0306)	(0.4487)*	(0.0302)	(0.4452)**
Basic metallic industries	0.2571	0.2472	0.2944	-1.2337	0.2931	-1.4694
	(0.0740)***	(0.0736)***	(0.0835)***	(0.7408)*	(0.0829)***	(0.7360)**
Metallic products, machines, equipment	0.1424	0.1213	0.1714	-1.0174	0.1506	-1.1025
	(0.0236)***	(0.0236)***	(0.0248)***	(0.2850)***	(0.0247)***	(0.2833)***
Other manufacturing industries	0.3600	0.3459	0.3763	-1.1373	0.3636	-1.2425
	(0.0466)***	(0.0463)***	(0.0490)***	(0.4494)**	(0.0485)***	(0.4465)***

Standard errors in parentheses. *** Significant at the p = 0.01 level. ** Significant at the p = 0.05 level. * Significant at the p = 0.1 level.

Table 2.5.3 (a). Location of manufacturing (state) main fixed effects and interactions with foreign ownership
(Base values: "Aguascalientes" and "No foreign ownership")

	Without interactions		With interactions			
	Main effects		Main	Interact	Main	Interact
State	OLS	SF	OLS		SF	
BC	0.5466	0.5239	0.5598	-0.4708	0.5362	-0.4374
	(0.0601)***	(0.0599)***	(0.0674)***	(0.8814)	(0.0669)***	(0.8823)
BCS	0.2192	0.1716	0.2000	0.0760	0.1505	0.0030
	(0.0962)**	(0.0956)*	(0.0988)**	(1.5959)	(0.0978)	(1.5788)
CMP	0.0608	0.0179	0.0647	-4.7132	0.0190	-4.9973
	(0.0951)*	(0.0946)	-0.0947	(14.0774)	(0.0939)	(13.8013)
COA	0.4339	0.4043	0.3933	0.2451	0.3633	0.2441
	(0.0590)***	(0.0588)***	(0.0617)***	(0.8955)	(0.0612)***	(0.8959)
COL	0.1472	0.0972	0.1402	4.3718	0.0860	4.5826
	(0.0875)*	(0.0869)	-0.0875	(5.6597)	(0.0866)	(5.5611)
CHS	0.1547	0.1145	0.1501	2.0456	0.1049	2.1469
	(0.0752)**	(0.0749)	(0.0753)**	(2.3546)	(0.0748)	(2.3919)
CHI	0.4969	0.4507	0.5487	-0.2780	0.4943	-0.2015
	(0.0595)***	(0.0594)***	(0.0626)***	(0.8807)	(0.0622)***	(0.8822)
DF	0.8445	0.8003	0.8123	0.1635	0.7619	0.2355
	(0.0539)***	(0.0539)***	(0.0553)***	(0.9348)	(0.0552)***	(0.9345)
DGO	0.2899	0.2559	0.2834	-0.6105	0.2475	-0.6320
	(0.0694)***	(0.0690)***	(0.0702)***	(1.4071)	(0.0696)***	(1.4032)
GTO	0.5907	0.5429	0.5707	0.4820	0.5158	0.6082
	(0.0572)***	(0.0571)***	(0.0581)***	(0.9437)	(0.0578)***	(0.9398)
GRO	0.3896	0.3608	0.3998	-1.4905	0.3668	-0.9467
	(0.0800)***	(0.0795)***	(0.0802)***	(3.4986)	(0.0795)***	(3.4852)
HGO	0.4617	0.4197	0.4352	1.2647	0.3881	1.2417
	(0.0650)***	(0.0647)***	(0.0654)***	(1.0940)	(0.0649)***	(1.0931)
JAL	0.7581	0.7156	0.7373	0.3152	0.6890	0.3895
	(0.0542)***	(0.0541)***	(0.0552)***	(0.9233)	(0.0549)***	(0.9226)
MEX	0.9103	0.8669	0.8411	0.8365	0.7899	0.9330
	(0.0540)***	(0.0540)***	(0.0560)***	(0.8905)	(0.0558)***	(0.8916)
MICH	0.3821	0.3374	0.3988	-1.9846	0.3497	-2.0579
	(0.0615)***	(0.0612)***	(0.0619)***	(1.1962)	(0.0614)***	(1.1912)
MOR	0.4797	0.4382	0.4579	0.7952	0.4103	0.8730
	(0.0707)***	(0.0704)***	(0.0728)***	(0.9667)	(0.0722)***	(0.9686)

Standard errors in parentheses. *** Significant at the p = 0.01 level. ** Significant at the p = 0.05 level. * Significant at the p = 0.1 level.

Table 2.5.3 (b). Location of manufacturing (state) main fixed effects and interactions with foreign ownership

(Base values: "Aguascalientes" and "No foreign ownership")

	Without interactions		With interactions			
	Main effects		Main	Interact	Main	Interact
State	OLS	SF	OLS		SF	
NAY	0.4215	0.3727	0.3971	0.4081	0.3421	0.5236
	(0.0875)***	(0.0870)***	(0.0880)***	(1.4538)	(0.0872)***	(1.4847)
NL	0.7840	0.7367	0.7780	-0.2136	0.7256	-0.1620
	(0.0551)***	(0.0551)***	(0.0570)***	(0.9052)	(0.0567)***	(0.9055)
OAX	0.2491	0.2169	0.2305	1.5901	0.1938	1.4390
	(0.0724)***	(0.0720)***	(0.0729)***	(1.4004)	(0.0722)***	(1.3782)
PUE	0.6161	0.5846	0.6035	0.4037	0.5683	0.4064
	(0.0571)***	(0.0568)***	(0.0580)***	(0.9634)	(0.0575)***	(0.9639)
QRO	0.6407	0.5946	0.5958	0.7067	0.5442	0.7239
	(0.0649)***	(0.0647)***	(0.0679)***	(0.9282)	(0.0674)***	(0.9290)
QR	0.6799	0.6322	0.6501	4.0684	0.5961	3.9772
	(0.0926)***	(0.0920)***	(0.0927)***	(1.9124)	(0.0918)***	(1.8864)
SLP	0.5147	0.4748	0.5033	0.4926	0.4616	0.4671
	(0.0616)***	(0.0613)***	(0.0625)***	(0.9570)	(0.0620)***	(0.9562)
SIN	0.6042	0.5592	0.5922	1.0790	0.5433	1.0744
	(0.0658)***	(0.0655)***	(0.0662)***	(1.4085)	(0.0657)***	(1.3975)
SON	0.8023	0.7595	0.7438	-0.0307	0.6937	0.0356
	(0.0616)***	(0.0614)***	(0.0644)***	(0.8891)	(0.0640)***	(0.8900)
TAB	0.4175	0.3763	0.4056	13.8354	0.3600	13.7799
	(0.0860)***	(0.0854)***	(0.0859)***	(11.1927)	(0.0850)***	(11.2049)
TMS	0.7159	0.6807	0.7000	0.0618	0.6622	0.1273
	(0.0617)***	(0.0614)***	(0.0660)***	(0.8775)	(0.0655)***	(0.8788)
TLX	0.4299	0.3837	0.4400	-0.5039	0.3889	-0.5027
	(0.0771)***	(0.0766)***	(0.0789)***	(1.1571)	(0.0781)***	(1.1474)
VER	0.4860	0.4509	0.4768	0.5291	0.4362	0.6621
	(0.0609)***	(0.0605)***	(0.0616)***	(0.9537)	(0.0610)***	(0.9513)
YUC	0.5792	0.5460	0.5941	-1.1393	0.5562	-1.0593
	(0.0632)***	(0.0629)***	(0.0637)***	(1.0685)	(0.0631)***	(1.0582)
ZAC	0.2935	0.2493	0.3024	-1.8561	0.2538	-1.8272
	(0.0815)***	(0.0809)***	(0.0823)***	(1.7577)	(0.0815)***	(1.7736)

Standard errors in parentheses. *** Significant at the p = 0.01 level. ** Significant at the p = 0.05 level. * Significant at the p = 0.1 level.

Appendix 3

Table 3.2.1. Mexico: Data on Maquiladora Activity 1990, 1995, 2000

Item	1990	1995	2000
Employment as a percent of manufacturing employment	4.0	4.6	8.7
Employment as a percent of economically-active population	1.7	2.0	3.8
Gross value added as a percent of manufacturing GDP	4.8	6.5	8.7
Gross value added as a percent of total GDP	0.9	1.3	1.9
Exports as a percent of manufacturing exports	49.0[1]	46.2	54.2
Exports as a percent of total exports	37.1[1]	39.1.2	47.7

Source: INEGI, Banco de Información Económica, Censo General de Población y Vivienda 1990, Conteo General de Población y Vivienda 1995, and Censo General de Población y Vivienda 2000, www.inegi.gob.mx.

[1] It refers to 1991.

Table 3.2.2. Mexico: Average Annual Percent Changes 1991-1995, 1996-2000

Item	1991-1995	1996-2000
Gross Domestic Product	1.6	5.4
Manufacturing GDP	1.2	7.8
Exports[1]	25.5	16.0
Foreign Direct Investment[1]	25.7	20.5
Maquiladora employment	6.8	15.8
Maquiladora gross value added[2]	7.0	14.3
Maquiladora exports	18.4[3]	21.2[1]

Source: INEGI, Banco de Información Económica, www.inegi.gob.mx.

[1] In current U.S. dollars.

[2] In constant 1993 Mexican pesos.

[3] It refers to 1991-1995.

Table 3.2.3. Mexico: Manufacturing Gross Value Added Growth Accounting 1995-2000

Year	Share of maquil in total manufacturing	Manufacturing growth rate (%)	Maquiladora growth rate (%)	Contribution of maquil growth to manufacturing growth (%)
1995	0.0916	41.0	48.7	10.9
1996	0.0992	39.4	51.0	12.9
1997	0.1206	19.9	45.7	27.7
1998	0.1380	19.6	36.8	26.0
1999	0.1589	15.8	33.4	33.5
2000	0.1809	13.6	29.3	38.9

Source: Author's calculations based on data from the Sistema de Cuentas Nacionales de México (INEGI).

Table 3.5.1 (a). Mexico: State summary statistics (by year)

Year	1980			1990			2000		
Item	N	Mean	St. Dev.	N	Mean	St. Dev.	N	Mean	St. Dev.
Maq payroll employment (employees)	32	7,060	25,667	32	14,071	35,405	32	40,164	79,269
Maq gross value added (1993 MXN)	32	1,029	3,821	32	308,422	785,794	32	859,553	1,791,858
Maq payroll employment per capita (employees)	32	0.0052	0.0212	32	0.0068	0.0162	32	0.0158	0.0292
Maq gross value added per capita (1993 MXN)	32	0.0008	0.0032	32	0.1449	0.3602	32	0.3233	0.6546
Literacy rate (15 or older)	32	0.825	0.090	32	0.873	0.069	32	.904	0.054
Elementary school enrollment rate	32	0.720	0.081	32	0.836	0.056	32	0.854	0.040
Secondary school enrollment rate	32	0.334	0.065	32	0.396	0.094	32	0.499	0.091
High school enrollment rate	32	0.170	0.043	32	0.222	0.064	32	0.267	0.063
Undergraduate school enrollment rate	32	0.031	0.017	32	0.085	0.029	32	0.110	0.029
House with tap water rate	32	0.122	0.029	32	0.158	0.028	32	0.250	0.082
House with electric power rate	32	0.107	0.036	32	0.172	0.020	32	0.380	0.048
House with drainage rate	32	0.075	0.031	32	0.119	0.033	32	0.730	0.128
Life expectancy rate	32	69.284	2.518	32	71.331	1.214	32	74.022	0.796
Infant mortality rate	32	38.057	14.587	32	35.972	6.499	32	22.973	3.551
Real GDP per capita growth rate (5 prior years)	32	8.24%	4.35%	32	1.47%	4.84%	32	4.94%	1.76%
Average earnings (current MXN)	32	3.936	1.559	32	20.376	4.198	32	94.208	22.377
Index of Modified Human Development	32	0.706	0.062	32	0.777	0.058	32	0.807	0.055

Source: Author's calculations based on data from the Censo General de Población y Vivienda 1980, 1990, and 2000, Sistema de Cuentas Nacionales de México (INEGI), Instituto Mexicano del Transporte, and the UNDP.

Table 3.5.1 (b). Mexico: State summary statistics 1980, 1990, 2000 (Total)

Item	N	Mean	St. Dev.
Maq payroll employment (employees)	96	20,432	53,661
Maq gross value added (1993 MXN)	96	389,668.2	1,173,324
Maq payroll employment per capita (employees)	96	0.0093	0.0231
Maq gross value added per capita (1993 MXN)	96	0.1563	0.4469
Literacy rate (15 or older)	96	0.868	0.079
Elementary school enrollment rate	96	0.803	0.085
Secondary school enrollment rate	96	0.409	0.108
High school enrollment rate	96	0.219	0.069
Undergraduate school enrollment rate	96	0.075	0.042
House with tap water rate	96	0.176	0.075
House with electric power rate	96	0.220	0.122
House with drainage rate	96	0.308	0.310
Life expectancy rate	96	71.546	2.561
Infant mortality rate	96	32.334	11.504
Real GDP per capita growth rate (5 prior years)	96	4.88%	4.75%
Average earnings (current MXN)	96	39.507	41.561
Index of Modified Human Development	96	0.763	0.072

Source: Author's calculations based on data from the Censo General de Población y Vivienda 1980, 1990, and 2000, Sistema de Cuentas Nacionales de México (INEGI), Instituto Mexicano del Transporte, and the UNDP.

Table 3.5.2. Dependent Variable: Log Literacy Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.855	-0.022	-0.383	-0.035	-0.238	-0.224	-0.130	-0.036
	(105.81)***[4]	(0.37)	(5.03)***	(0.47)	(2.47)**	(8.03)***	(0.72)	(0.74)
Per-Capita Maq Employ	1.299							
	(3.98)***							
Pred Log PC Maq Employ		0.015	0.005	0.010	0.005	0.005	0.098	0.018
		(4.20)***	(2.26)**	(1.66)	(0.60)	(2.88)***	(0.90)	(6.11)**
Log Average Earnings		0.012	0.213	0.014	0.123	0.115	0.089	0.105
		(1.40)	(6.26)***	(1.63)	(4.56)***	(15.26)***	(1.83)*	(9.54)***
Per-Cap GDP Growth Rate		-0.150	-0.303	-0.176	-0.168	-0.173	-0.090	n/a[5]
		(1.06)	(2.44)**	(1.53)	(0.99)	(6.92)***	(0.65)	
Pred Log PC Maq Employ*d90							-0.002	-0.001
							(0.28)	(0.57)
Pred Log PC Maq Employ*d00							-0.006	-0.030
							(0.82)	(9.76)***
Log Avg Earn*d90							-0.048	-0.045
							(2.92)***	(6.25)***
Log Avg Earn*d00							-0.063	-0.125
							(3.10)***	(18.44)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						11186.39		45429.45
Hausman χ^2		3.90						
Log Likelihood						297.504		339.691
R^2	0.144	0.404	0.780	0.904	0.954		0.954	

[1] Literacy rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.3. Dependent Variable: Log Elementary School Enrollment Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.794	-0.210	-0.534	0.121	-0.423	-0.377	-0.218	-0.151
	(87.86)***[4]	(3.73)***	(5.90)***	(0.60)	(3.68)**	(11.83)***	(0.74)	(3.29)***
Per-Capita Maq Employ	1.065							
	(2.92)***							
Pred Log PC Maq Employ		0.011	0.003	0.031	0.007	0.010	0.016	0.027
		(3.34)***	(1.08)	(2.11)**	(0.70)	(5.32)***	(0.96)	(9.00)***
Log Average Earnings		0.040	0.202	0.003	0.172	0.166	0.106	0.153
		(5.11)***	(5.17)***	(0.14)	(4.07)***	(15.34)***	(1.30)	(15.01)***
Per-Cap GDP Growth Rate		-0.438	-0.279	-0.693	-0.223	-0.252	-0.070	n/a[5]
		(2.57)**	(2.14)**	(2.28)**	(1.03)	(6.83)***	(0.48)	
Pred Log PC Maq Employ*d90							-0.007	-0.001
							(0.68)	(0.70)
Pred Log PC Maq Employ*d00							-0.010	-0.037
							(0.92)	(11.36)***
Log Avg Earn*d90							0.502	-0.086
							(1.56)	(6.91)***
Log Avg Earn*d00							0.072	-0.161
							(1.92)*	(19.23)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						23183.92		24648.52
Hausman χ^2		1.58						
Log Likelihood						268.696		301.716
R^2	0.083	0.632	0.827	0.6117	0.943		0.925	

[1] Secondary school enrollment rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.4. Dependent Variable: Log Secondary School Enrollment Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.393	-1.026	-1.524	-1.654	-0.627	-0.639	-1.505	-0.886
	(35.64)***[4]	(6.33)***	(5.45)***	(4.55)***	(2.65)**	(6.14)***	(1.81)*	(5.08)***
Per-Capita Maq Employ	1.759							
	(3.95)***							
Pred Log PC Maq Employ		0.024	0.009	-0.024	0.013	0.016	-0.027	-0.000
		(2.72)***	(0.98)	(0.81)	(0.63)	(2.79)***	(0.52)	(0.01)
Log Average Earnings		0.105	0.394	0.165	-0.253	-0.225	0.060	-0.167
		(4.52)***	(3.63)***	(4.11)***	(1.80)*	(7.31)***	(0.30)	(3.61)***
Per-Cap GDP Growth Rate		0.549	0.144	0.678	0.156	0.259	-0.477	n/a[5]
		(1.32)	(0.28)	(1.33)	(0.31)	(1.43)***	(0.88)	
Pred Log PC Maq Employ*d90							0.043	-0.015
							(1.17)	(1.60)
Pred Log PC Maq Employ*d00							0.031	0.008
							(0.89)	(0.72)
Log Avg Earn*d90							0.172	0.444
							(1.82)*	(14.81)***
Log Avg Earn*d00							0.124	0.220
							(1.63)	(7.24)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						5158.84		240051.16
Hausman χ^2		1.07						
Log Likelihood						158.928		186.957
R^2	0.142	0.574	0.665	0.833	0.902		0.876	

[1] Secondary school enrollment rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.5. Dependent Variable: Log High School Enrollment Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.212	-1.861	-1.917	-2.520	-0.372	-0.116	-1.903	-1.384
	(28.67)***4	(9.87)***	(4.34)***	(4.62)***	(0.77)	(0.48)	(1.32)	(4.75)***
Per-Capita Maq Employ	0.808							
	(2.71)***							
Pred Log PC Maq Employ		0.013	0.012	-0.037	0.006	0.021	-0.056	-0.032
		(1.36)	(0.82)	(0.80)	(0.13)	(1.26)	(0.65)	(1.75)*
Log Average Earnings		0.132	0.142	0.195	-1.083	-1.113	-0.474	-0.649
		(4.10)***	(0.83)	(3.44)***	(4.58)***	(22.38)***	(1.28)	(12.29)***
Per-Cap GDP Growth Rate		0.578	0.915	0.681	1.085	0.640	-0.022	n/a[5]
		(1.06)	(1.27)	(0.83)	(1.27)	(2.17)**	(0.04)	
Pred Log PC Maq Employ*d90							0.056	0.009
							(0.94)	(0.87)
Pred Log PC Maq Employ*d00							0.038	0.041
							(0.65)	(2.14)**
Log Avg Earn*d90							0.591	0.883
							(3.69)***	(16.84)***
Log Avg Earn*d00							0.565	0.667
							(3.84)***	(15.11)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						5429.98		10838.76
Hausman χ^2		0.00						
Log Likelihood						99.624		140.596
R^2	0.073	0.391	0.397	0.550	0.796		0.765	

[1] High school enrollment rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.6. Dependent Variable: Log College Enrollment Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.071	-3.322	-4.564	-2.590	-4.810	-4.651	-5.211	-4.792
	(16.00)***[4]	(11.69)***	(11.59)***	(3.25)***	(8.03)***	(31.54)***	(4.20)***	(13.44)***
Per-Capita Maq Employ	0.468							
	(2.61)***							
Pred Log PC Maq Employ		0.039	0.010	0.082	-0.053	-0.051	-0.068	-0.025
		(2.31)**	(0.61)	(1.41)	(1.08)	(4.84)***	(0.91)	(1.13)
Log Average Earnings		0.357	0.945	0.264	0.566	0.460	0.753	0.849
		(10.00)***	(5.60)***	(2.76)***	(5.49)***	(8.87)***	(2.43)**	(10.56)***
Per-Cap GDP Growth Rate		-2.444	-1.263	-3.396	-0.055	-0.012	-0.293	n/a[5]
		(4.68)***	(4.46)***	(3.25)***	(0.06)	(0.05)	(0.34)	
Pred Log PC Maq Employ*d90							0.030	0.035
							(0.67)	(2.48)**
Pred Log PC Maq Employ*d00							-0.006	-0.098
							(0.12)	(6.17)***
Log Avg Earn*d90							0.076	0.031
							(0.80)	(0.89)
Log Avg Earn*d00							-0.184	-0.453
							(1.59)**	(13.24)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						22129.77		83456.24
Hausman χ^2		1.74						
Log Likelihood						139.199		167.826
R^2	0.068	0.817	0.922	0.889	0.972		0.965	

[1] College enrollment rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.7. Dependent Variable: Log House with Tap Water Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.163	-1.917	-2.544	-2.855	-1.921	-2.074	-1.926	-2.406
	(21.79)***[4]	(10.56)***	(11.43)***	(4.47)***	(2.99)***	(8.37)***	(2.02)**	(6.28)***
Per-Capita Maq Employ	1.399							
	(4.62)***							
Pred Log PC Maq Employ		0.041	0.020	-0.046	-0.000	-0.006	0.009	-0.067
		(3.86)***	(2.21)**	(0.95)	(0.01)	(0.34)	(0.15)	(3.23)***
Log Average Earnings		0.167	0.554	0.285	0.029	0.080	-0.038	-0.249
		(6.08)***	(6.80)***	(3.69)***	(0.21)	(1.44)	(0.16)	(2.60)***
Per-Cap GDP Growth Rate		0.316	-0.577	0.864	-0.065	0.034	-0.097	n/a[5]
		(0.62)	(1.10)	(1.36)	(0.07)	(0.08)	(0.15)	
Pred Log PC Maq Employ*d90							-0.016	-0.040
							(0.47)	(2.40)**
Pred Log PC Maq Employ*d00							-0.029	0.133
							(0.94)	(7.60)***
Log Avg Earn*d90							0.066	-0.034
							(0.88)	(0.83)
Log Avg Earn*d00							0.238	0.625
							(2.35)**	(25.95)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						3167.34		132138.71
Hausman χ^2		3.57						
Log Likelihood						107.274		166.678
R^2	0.185	0.688	0.810	0.856	0.922		0.938	

[1] House with tap water rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.8. Dependent Variable: Log House with Electric Power Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.205	-2.753	-3.192	-3.767	-3.430	-3.460	-2.355	-2.094
	(15.85)***[4]	(42.43)***	(20.71)***	(6.15)***	(7.26)***	(26.14)***	(2.20)**	(6.28)***
Per-Capita Maq Employ	1.576							
	(3.02)***							
Pred Log PC Maq Employ		0.012	-0.005	-0.067	-0.018	-0.027	0.036	0.070
		(3.14)***	(0.80)	(1.44)	(0.52)	(3.20)***	(0.57)	(3.48)***
Log Average Earnings		0.402	0.715	0.520	0.802	0.729	0.468	0.624
		(39.17)***	(10.87)***	(7.09)***	(5.27)***	(20.95)***	(1.69)	(8.70)***
Per-Cap GDP Growth Rate		0.247	-1.087	1.003	-0.714	-0.346	-0.020	n/a[5]
		(0.91)	(3.10)***	(1.80)	(1.38)	(1.61)	(0.04)	
Pred Log PC Maq Employ*d90							-0.043	-0.002
							(1.18)	(0.14)
Pred Log PC Maq Employ*d00							-0.051	-0.151
							(1.63)	(6.73)***
Log Avg Earn*d90							-0.261	-0.518
							(2.86)***	(9.28)***
Log Avg Earn*d00							-0.166	-0.485
							(1.45)	(11.26)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						18274.97		40136.39
Hausman χ^2		-15.49						
Log Likelihood						142.697		170.397
R^2	0.088	0.924	0.965	0.921	0.980		0.981	

[1] House with electric power rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.9. Dependent Variable: Log House with Drainage Rate[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.278	-3.991	-3.730	-7.738	-2.950	-3.063	-2.893	-2.662
	(8.35)***[4]	(23.78)***	(15.05)***	(3.74)***	(6.72)***	(15.34)***	(2.68)**	(15.60)***
Per-Capita Maq Employ	3.219							
	(2.39)**							
Pred Log PC Maq Employ		0.007	-0.001	-0.286	0.005	-0.000	0.020	0.104
		(0.81)	(0.14)	(1.87)*	(0.16)	(0.01)	(0.30)	(4.80)***
Log Average Earnings		0.741	0.851	1.197	0.542	0.570	0.640	0.702
		(32.45)***	(7.24)***	(4.86)***	(3.68)***	(9.44)***	(2.33)**	(8.82)***
Per-Cap GDP Growth Rate		3.528	-0.608	6.378	-0.813	-0.558	-0.896	n/a[5]
		(3.16)***	(1.55)	(2.36)***	(1.29)	(1.92)*	(1.18)	
Pred Log PC Maq Employ*d90							0.020	0.007
							(0.57)	(0.42)
Pred Log PC Maq Employ*d00							-0.032	-0.200
							(1.01)	(7.39)***
Log Avg Earn*d90							-0.170	-0.020
							(2.07)**	(0.25)
Log Avg Earn*d00							-0.022	-0.438
							(0.19)	(7.52)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						36190.65		157676.00
Hausman χ^2		-24.02						
Log Likelihood						111.827		136.294
R^2	0.057	0.889	0.976	0.644	0.991		0.990	

[1] House with drainage rate (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.10. Dependent Variable: Log Life Expectancy[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	71.248	4.239	4.169	4.195	4.160	4.178	4.168	4.292
	(262.76)***[4]	(284.94)***	(156.30)***	(88.79)***	(63.01)***	(182.97)***	(34.00)***	(82.97)***
Per-Capita Maq Employ	32.178							
	(2.94)***							
Pred Log PC Maq Employ		0.002	0.000	-0.002	-0.002	-0.003	-0.001	0.007
		(2.74)***	(0.38)	(0.46)	(0.40)	(1.67)*	(0.15)	(2.33)**
Log Average Earnings		0.019	0.060	0.024	0.053	0.032	0.052	0.038
		(7.26)***	(5.16)***	(4.12)***	(2.07)***	(5.07)***	(1.98)*	(3.16)***
Per-Cap GDP Growth Rate		0.015	-0.052	0.043	0.006	0.011	0.012	n/a[5]
		(0.33)	(0.88)	(1.10)	(0.09)	(0.24)	(0.13)	
Pred Log PC Maq Employ*d90							0.001	-0.001
							(0.27)	(0.41)
Pred Log PC Maq Employ*d00							0.001	-0.011
							(0.34)	(4.98)***
Log Avg Earn*d90							-0.015	-0.009
							(1.17)	(1.47)
Log Avg Earn*d00							-0.023	-0.039
							(2.14)**	(8.33)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						2642.86		17054.86
Hausman χ^2		4.13						
Log Likelihood						324.495		349.338
R^2	0.084	0.695	0.821	0.878	0.889		0.893	

[1] Life expectancy (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.11. Dependent Variable: Log Infant Mortality[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	33.560	3.644	3.641	5.096	3.237	3.108	4.442	5.272
	(27.35)***[4]	(27.98)***	(14.73)***	(7.12)***	(5.04)***	(21.94)***	(2.46)**	(15.68)***
Per-Capita Maq Employ	-132.322							
	(2.67)***							
Pred Log PC Maq Employ		-0.021	-0.016	0.081	-0.009	-0.014	0.050	0.124
		(3.29)***	(1.96)*	(1.45)	(0.27)	(2.58)***	(0.53)	(5.52)***
Log Average Earnings		-0.122	-0.196	-0.281	0.224	0.259	-0.165	-0.109
		(4.98)***	(1.76)*	(3.57)***	(0.68)	(9.43)***	(0.28)	(2.08)**
Per-Cap GDP Growth Rate		-1.487	-0.234	-2.716	-0.844	-0.598	0.033	n/a[5]
		(3.74)***	(0.59)	(2.52)**	(1.15)	(4.18)***	(0.05)	
Pred Log PC Maq Employ*d90							-0.060	-0.034
							(0.93)	(3.02)***
Pred Log PC Maq Employ*d00							-0.055	-0.158
							(0.84)	(6.05)***
Log Avg Earn*d90							-0.147	-0.578
							(0.87)	(8.11)***
Log Avg Earn*d00							-0.126	-0.416
							(0.49)	(6.77)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						16408.96		5564.22
Hausman χ^2		-243.24						
Log Likelihood						100.013		101.604
R^2	0.071	0.416	0.505	0.248	0.680		0.611	

[1] Infant mortality (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 3.5.12. Dependent Variable: Log Modified Index of Human Development[1]

Variables	(1)	(2)[2]	(3)[2]	(4)[2]	(5)[2]	(6)[3]	(7)[2]	(8)[3]
Constant	0.752	-0.226	-0.557	-0.242	-0.398	-0.403	-0.456	-0.296
	(103.81)***[4]	(3.56)***	(9.92)***	(3.33)***	(7.98)***	(20.40)***	(3.51)***	(4.83)***
Per-Capita Maq Employ	1.255							
	(4.29)***							
Pred Log PC Maq Employ		0.013	0.004	0.006	-0.002	-0.001	-0.005	0.004
		(3.39)***	(1.71)*	(1.13)	(0.46)	(0.45)	(0.67)	(1.23)
Log Average Earnings		0.028	0.204	0.030	0.066	0.075	0.085	0.044
		(3.20)***	(9.73)***	(3.33)***	(3.91)***	(11.31)***	(2.10)**	(3.10)***
Per-Cap GDP Growth Rate		-0.146	-0.153	-0.315	-0.136	-0.110	-0.173	n/a[5]
		(0.89)	(1.22)	(5.83)**	(1.81)*	(3.07)***	(1.77)*	
Pred Log PC Maq Employ*d90							0.004	-0.007
							(0.83)	(2.51)**
Pred Log PC Maq Employ*d00							0.002	-0.010
							(0.34)	(2.98)**
Log Avg Earn*d90							-0.002	0.030
							(0.19)	(3.28)***
Log Avg Earn*d00							-0.024	-0.023
							(1.45)	(3.44)***
State Fixed Effects		No	No	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		No	Yes	No	Yes	Yes	Yes	Yes
N	96	96	96	96	96	96	96	96
Wald χ^2						37239.13		30032.75
Hausman χ^2		8.53						
Log Likelihood						327.473		337.356
R^2	0.164	0.612	0.896	0.967	0.986		0.979	

[1] Modified Index of Human Development (not log) in model (1). [2] t-statistics computed using robust standard errors. [3] GLS estimator. [4] Absolute t-values in parenthesis for all models except (6) and (8). Absolute z-values for models (6) and (8). [5] Excluded to avoid collinearity. * Significant at the 0.1 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Appendix 4
Retention ratio

I define the retention ratio as:

$$p_i \equiv 1/(1+\theta a_i) \tag{4.48}$$

Then,

$$\frac{dp_i}{da_i} = -\frac{\theta}{(1+\theta a_i)^2} = -\Big(\frac{\theta}{1+\theta a_i}\Big)\Big(\frac{1}{1+\theta a_i}\Big)\Big(\frac{a_i}{a_i}\Big) \tag{4.49}$$

$$\frac{dp_i}{da_i} = -\frac{(1-p_i)p_i}{a_i} = \frac{p_i^2 - p_i}{a_i} \tag{4.50}$$

$$\frac{d(1-p_i)}{da_i} = \frac{(1+\theta a_i)\theta - \theta a_i \theta}{(1+\theta a_i)^2} = \frac{\theta + \theta^2 a_i - \theta^2 a_i}{1+\theta a_i} = \frac{\theta}{(1+\theta a_i)^2} \tag{4.51}$$

$$\frac{d(1-p_i)}{da_i} = \frac{(1-p_i)p_i}{a_i} = \frac{p_i - p_i^2}{a_i} \tag{4.52}$$

First-order conditions

The Hamiltonian is defined as:

$$\begin{aligned} H_i = u(c_i) + \lambda_{ii}[y(x_i) - c_i - a_i - \delta x_i(1-p_j) + \gamma\delta x_j(1-p_i)\Big)] \\ +\lambda_{ij}[y(x_j) - c_j - a_j - \delta x_j(1-p_i) + \gamma\delta x_i(1-p_j)] \end{aligned} \tag{4.53}$$

The first-order necessary conditions for the Hamiltonian to be maximized for each player and t are derived as follows. First, with respect to consumption:

$$\frac{\partial H_i}{\partial c_i} = u'(c_i) - \lambda_{ii} = 0 \tag{4.54}$$

Therefore:

$$u'(c_i) = \lambda_{ii} \tag{4.55}$$

And then with respect to appropriation:

$$\frac{\partial H_i}{\partial a_i} = \lambda_{ii}[-1 + \gamma\delta x_j \frac{\partial(1-p_i)}{\partial a_i}] + \lambda_{ij}[-\delta x_j \frac{\partial(1-p_i)}{\partial a_i}] = 0 \tag{4.56}$$

Using equation (4.52) above, one can derive a nice-looking expression for this first-order condition:

$$\lambda_{ii}\Big[\gamma\delta x_j\Big(\frac{p_i - p_i^2}{a_i}\Big)\Big] - \lambda_{ii} - \lambda_{ij}\Big[\delta x_j\Big(\frac{p_i - p_i^2}{a_i}\Big)\Big] = 0 \tag{4.57}$$

$$\lambda_{ii}\Big[\gamma\delta x_j\Big(\frac{p_i - p_i^2}{a_i}\Big)\Big] - \lambda_{ij}\Big[\delta x_j\Big(\frac{p_i - p_i^2}{a_i}\Big)\Big] = \lambda_{ii} \tag{4.58}$$

$$\delta x_j\ (\gamma\lambda_{ii} - \lambda_{ij})\Big(\frac{p_i - p_i^2}{a_i}\Big) = \lambda_{ii} \tag{4.59}$$

$$\frac{a_i}{p_i - p_i^2} = \delta x_j \frac{(\gamma\lambda_{ii} - \lambda_{ij})}{\lambda_{ii}} \tag{4.60}$$

Elasticity of substitution

The instantaneous elasticity of substitution is the reciprocal of the negative of the elasticity of the marginal utility.

To see this, consider two points in time t and s. The elasticity of substitution of consumption between them is defined as:

$$\sigma(c_t) \equiv -\frac{u'(c_s)/u'(c_t)}{c_s/c_t} \frac{d(c_s/c_t)}{d[u'(c_s)/u'(c_t)]} \tag{4.61}$$

Take the limit of the expression above as $s \to t$:

$$\lim_{s\to t} \sigma(c_t) = \sigma[c(t)] = -\lim_{s\to t} \frac{u'(c_s)/u'(c_t)}{c_s/c_t} \times \lim_{s\to t} \frac{d(c_s/c_t)}{d[u'(c_s)/u'(c_t)]} \tag{4.62}$$

$$\sigma[c(t)] = -\frac{\lim_{s\to t}[u'(c_s)/u'(c_t)]}{\lim_{s\to t}[c_s/c_t]} \times \lim_{s\to t} \frac{d(c_s/c_t)}{d[u'(c_s)/u'(c_t)]} \tag{4.63}$$

$$\sigma[c(t)] = -\frac{1}{1} \times \lim_{s\to t} \frac{d(c_s/c_t)}{d[u'(c_s)/u'(c_t)]} \tag{4.64}$$

$$\sigma[c(t)] = -\frac{\lim_{s\to t} d(c_s/c_t)}{\lim_{s\to t} d[u'(c_s)/u'(c_t)]} \tag{4.65}$$

$$\sigma[c(t)] = -\frac{\lim_{s\to t} \frac{c_t(dc_s/dc_t)dc_t - c_s dc_t}{c_t^2}}{\lim_{s\to t} \frac{u'(c_t)[du'(c_s)/du'(c_t)]u''(c_t)dc_t - u'(c_s)[u''(c_t)]dc_t}{[u'(c_t)]^2}} \tag{4.66}$$

$$\sigma[c(t)] = -\frac{\lim_{s\to t} -(c_s/c_t)(dc_t/c_t)}{\lim_{s\to t} -[u'(c_s)/u'(c_t)][u''(c_t)/u'(c_t)]dc_t} \tag{4.67}$$

$$\sigma[c(t)] = -\frac{\lim_{s\to t}(dc_t/c_t)}{\lim_{s\to t}[u''(c_t)/u'(c_t)]dc_t} \tag{4.68}$$

$$\sigma[c(t)] = -\frac{[1/c(t)]}{u''[c(t)]/u'[c(t)]} \tag{4.69}$$

$$\sigma[c(t)] = -\frac{u'[c(t)]}{c(t)u''[c(t)]} \tag{4.70}$$

Since $\epsilon \equiv \{u''[c(t)]c(t)\}/u'[c(t)]$ is the elasticity of the marginal utility, then:

$$\sigma[c(t)] = -\frac{1}{\epsilon} \tag{4.71}$$

Markovian Nash equilibrium

The Markovian Nash optimal consumption rule at t follows directly from first-order condition (4.55).

The similar appropriation rule for a_i can be derived directly from equation (4.49) and simplifying first-order condition (4.60):

$$\frac{(1+\theta a_i)^2}{\theta} = \delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right) \tag{4.72}$$

$$(1+\theta a_i)^2 = \theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right) \tag{4.73}$$

$$1+\theta a_i = \pm\sqrt{\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right)} \tag{4.74}$$

$$\theta a_i = \pm\sqrt{\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right)} - 1 \tag{4.75}$$

$$a_i = \frac{1}{\theta}\left[\pm\sqrt{\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right)} - 1\right] \tag{4.76}$$

The nonnegativity condition for a_i requires that:

$$\pm\sqrt{\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right)} \geq 1 \tag{4.77}$$

The plus-minus sign can be dropped, since only the positive square root case satisfies the condition:

$$\sqrt{\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right)} \geq 1 \tag{4.78}$$

$$\theta\delta x_j \left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right) \geq 1 \tag{4.79}$$

$$\left(\frac{\gamma\lambda_{ii} - \lambda_{ij}}{\lambda_{ii}}\right) \geq \frac{1}{\theta\delta x_j} \tag{4.80}$$

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