

# Rational Underdevelopment\*

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## Abstract

We propose a two-region two-sector model of uneven development, where technological change benefits either the lagging or the leading region. In this framework interregional transfers may lead to persistent underdevelopment; by raising wages, transfers reduce the chance of the backward region adopting a new technology and taking off. Due to uncertainty about which region benefits from technological change, the backward region may rationally choose to remain underdeveloped, while the advanced region continues to pay transfers. The model provides a rationale for cases, such as Italy's *Mezzogiorno*, where the same rich region subsidizes the same poor region on a continuous basis.

*Keywords:* Interregional transfers; regional policy; uneven development

*JEL classification:* R58; H7

## I. Introduction

Interregional transfers that raise wages without improving productivity have often been blamed for keeping backward regions trapped in underdevelopment. By eroding the competitiveness of lagging regions, such transfers contribute to their inability to take off. The standard textbook example is southern Italy, where the postwar convergence of the *Mezzogiorno* went into reverse at the beginning of the 1970s, when public policy shifted from investment incentives to income support; see Paci and Sabo (1998) and Boltho, Carlino and Scaramozzino (1997). As a result, between 1971 and 1990, unit labor costs in the south rose 23% more than in the north, while relative GDP per capita in the former declined from 0.65 to 0.57.

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Post-reunification Germany tells much the same story. Heavy subsidies and union wage setting resulted in a tenfold jump in relative eastern wages—from 7% in 1991 to 70% in 1998—with relative labor productivity only increasing from 35% to 55%; see Sinn (2000). It did not take long for the new *Länder* to earn the dubious distinction of being called the *Mezzogiorno on the Elbe*. A similar picture emerges from a European-wide study by Padoa Schioppa and Basile (2002). They find that peripheral countries, such as Spain or Ireland, have been catching up faster than peripheral regions, such as southern Italy or eastern Germany. Padoa Schioppa and Basile (2002) point to an already familiar culprit: national unions constrain wages to be the same across regions *within* countries. As this leads to higher unemployment in peripheral regions, union wages increase the demand for interregional transfers, thereby preventing peripheral regions from taking off.<sup>1</sup> Since unions do not have the same power to set uniform wages across countries, peripheral countries do not undergo the same fate.

It seems hard to make sense of transfers that lock backward regions into underdevelopment. Why would the south be willing to accept transfers if they imply giving up the possibility of taking off? And why would the north want to pump money into a bottomless well? The contribution of this paper is to show how such transfers can be rationalized. That transfers may have a negative impact on development in the backward region is well known; how they can be sustained in equilibrium is not.

To analyze this issue, we propose a two-period model of uneven regional development inspired by Brezis, Krugman and Tsiddon (1993) and Desmet (2002). In the first period, the economy is divided into a rich manufacturing North and a poor agricultural South. In the second period, we introduce a new manufacturing technology, which can locate either in the backward South—attracted by its low wages—or in the advanced North—if spillovers from the previous technology are sufficiently strong to compensate for higher wages. Interregional transfers raise wages in the backward region, thus reducing its chance to adopt the new technology and take off. With high enough transfers, the backward South never adopts the new technology, and is doomed to remain backward.

The main result of the paper is that transfers which condemn the backward region to underdevelopment may Pareto dominate (lower) transfers that give the backward region a chance to take off. This is what we call *rational underdevelopment*. The advanced region gives transfers to protect itself against low-wage competition, thus preventing the backward region

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<sup>1</sup> In the case of Italy, regional differentials in collective labor contracts ceased to be allowed at the end of the 1960s. Several authors have blamed the lackluster behavior of the *Mezzogiorno* on this policy change; see Faini (1995) and Brunello, Lupi and Ordine (2001).

from taking off and ensuring its dominant position; the backward region accepts these transfers—and rationally chooses to remain backward—because even without transfers it is not sure to benefit from the new technology. To illustrate our theoretical findings, we provide some numerical examples, and show that rational underdevelopment is consistent with reasonable parameter values. Our motivating examples and our focus are on the effects of transfers between regions within developed countries, and not on transfers between rich and poor countries.

Our paper is related to the well-known transfer paradox, dating back to Leontieff (1936). This paradox refers to the possibility of transfers benefiting the donor through an improvement in its terms of trade. If the gains from more favorable terms of trade are enough to compensate the losses from paying transfers, the donor ends up better off. Although this suffices to show why rich regions or countries may be interested in paying transfers, it falls short in explaining why their poor counterparts are willing to accept them.

The same failure to endogenize transfers is revealed in Desmet (2002), which is limited to showing how transfers can make backward regions worse off; it remains silent on whether such policies could be sustained in equilibrium. This is also true for empirical work on the *Mezzogiorno* and eastern Germany by Boltho *et al.* (1997), Alesina, Danninger and Rostagno (1999), Sinn (2000) and Sinn and Westermann (2001). If anything, the common tone is that such regional policies have been misplaced. Our paper claims this is not necessarily the case.

There are, of course, models that explain why transfers arise in equilibrium. A first class of such models argues that interregional transfers can be used to solve a fiscal externality problem. Of particular interest is Wildasin (1994), who shows that local redistributive policies in the rich region may lead to an inefficiently high level of migration. In this case, using transfers to stem migration may make everyone better off. However, unlike in our paper, distortionary public policy is a precondition for transfers to be Pareto improving. A second class of models argues that transfers can be justified as a risk-sharing device against asymmetric shocks; see Alesina and Perotti (1998) and Persson and Tabellini (1996a,b). Asymmetric shocks imply two-way transfers: region *A* is willing to subsidize region *B* because at some future date *B* will subsidize *A*. This setup can therefore not explain the *Mezzogiorno* problem: one-way transfers, where the same rich region subsidizes the same poor region on a continuous basis. A third class of models claims that a rich region may be willing to pay transfers to a poor region, because the cost of transfers is compensated by the benefit of a more efficient provision of public goods; see Bolton and Roland (1997). However, none of these papers studies the effect of transfers on the development prospects of the backward regions.

Summing up, the literature that explains how transfers keep lagging regions backward is unable to rationalize them, as in Leontieff (1936) and Desmet (2002), whereas the literature that rationalizes transfers does not explain how they keep lagging regions backward, as in Myers (1990), Wildasin (1994), Persson and Tabellini (1996a) and Bolton and Roland (1997). The contribution of our paper is to tackle both issues simultaneously. We show how transfers that harm the development prospects of a backward region may be rational. The North ensures that it remains in the lead, whereas the South prefers the certainty of transfers to the uncertainty of taking off.

The motives that give rise to transfers in our model require some further justification. Post-reunification Germany provides a good illustration of what we have in mind. The first part of our argument says that the rich region is willing to pay transfers, because it is worried about low wage competition. Akerlof, Rose, Yellen, Hessenius, Dornbusch and Guitian (1991) claim that western German unions pushed for wage equality, because they were worried about firms moving east, and workers moving west. They quote the journal of the German trade unions, *Die Quelle*, as arguing that the absence of wage parity would drive down western wages. They also provide evidence of western auto workers expressing their concern about worsening conditions after Volkswagen established new facilities in the east. Sinn and Sinn (1992) note that western German capital owners were also often in favor of wage parity, as this would protect the value of past investments in the west. They quote the chairman of the Metal Trades Employers Association as “vigorously” defending eastern wage increases.

The second part of our argument says that the poor region is willing to accept transfers, because it prefers the certainty of transfers to the uncertainty of take off. Eastern Germans seemed content to go along with wage parity. This was not out of ignorance. According to a survey by Akerlof *et al.* (1991), a full 80% of eastern Germans understood that their wages were increasing faster than their productivity. Moreover, they were aware that such policies could have detrimental effects on employment. In a poll conducted by the Allensbach Institute in 1990, only 45% of east Germans thought their firm would survive; see Akerlof *et al.* (1991). In spite of this dismal outlook, eastern workers preferred wage equality. Transfers in the form of unemployment benefits provide a convincing explanation to this apparent puzzle; see Akerlof *et al.* (1991) and Sinn and Sinn (1992). Since German unemployment benefits depend on terminal wages, workers may have preferred a significant, though brief, wage increase, before becoming unemployed. This arrangement may have benefited eastern Germans in two ways: it increased their income under the bad outcome of unemployment, and it may also have raised their expected income.

A relevant question is whether there is anything that makes a region different from a country. While our theoretical model does not differentiate between the two, the focus is clearly on regions *within* countries. Indeed, the motivating examples and the numerical exercises refer to regions. In addition, the policy instruments we have in mind, such as wage subsidies or unemployment benefits, are more fitting for transfers between regions.

The rest of the paper is organized as follows. In Section II we introduce the theoretical model and give conditions under which rational underdevelopment may occur. Section III provides some numerical examples. Section IV concludes.

## II. The Model

The basic structure of the model closely follows Brezis *et al.* (1993) and Desmet (2002). Consider two regions, North and South. Variables that refer to the South are denoted by an asterisk. Labor is the only factor of production and is geographically immobile. While criticizable in the case of the U.S., this latter assumption seems reasonable in the European context. The size of the labor force is the same in both regions:

$$L = L^* = 1.$$

Let  $Q_F$  ( $Q_M$ ) denote output of food (manufactures), and  $L_F$  ( $L_M$ ) labor employed in food (manufactures). Food technologies are identical in North and South:

$$Q_F = L_F \tag{1}$$

$$Q_F^* = L_F^*. \tag{2}$$

Manufacturing production, however, is subject to region-specific learning externalities, so that manufacturing technologies differ across regions:

$$Q_M = AL_M \tag{3}$$

$$Q_M^* = A^*L_M^*. \tag{4}$$

Food and manufacturing should not be interpreted literally; they are metaphors for a sector with no learning and a sector with learning. All consumers have identical preferences:

$$U(C_M, C_F) = v(C_M^\mu C_F^{1-\mu}), \tag{5}$$

where  $v$  is a strictly increasing and strictly concave function,  $C_F$  and  $C_M$  denote the consumption of food and manufactures, and  $\mu > 1/2$ .<sup>2</sup> Consumers,

<sup>2</sup>This ensures uneven development between both regions. Without this assumption, both regions would produce food, and wages would equalize.

therefore, are risk averse, and spend a fraction  $\mu$  of their income on manufactures. After normalizing the food price to 1, the inverse demand function of manufactures relative to food is:

$$\frac{C_M}{C_F} = \frac{\mu}{1 - \mu} \frac{1}{p_M}, \quad (6)$$

where  $p_M$  denotes the manufacturing price.

The model consists of two periods: in period 1 productivity differences lead the economy to diverge into a rich manufacturing North and a poor agricultural South; in period 2 a new manufacturing technology is introduced, which either reinforces or reverses this pattern of uneven development. In what follows we study each period in turn.

### *Period 1*

In period 1 the economy is fully specialized: the North produces manufactures and the South produces food. Plugging production into (6) gives us the equilibrium manufacturing price:

$$p_M = \frac{\mu}{1 - \mu} \frac{1}{A}. \quad (7)$$

For full specialization to be an equilibrium, no one in the South should have an incentive to switch to manufacturing production, so that:

$$1 > \frac{\mu}{1 - \mu} \frac{A^*}{A}. \quad (8)$$

In other words, the productivity advantage of the North needs to be sufficiently large compared to the relative importance of manufacturing consumption, so that the North is able to satisfy on its own all of the manufacturing demand in the economy. Likewise, no workers in the North should have an incentive to switch to food; this result is immediate, since  $\mu > 1/2$ . Given the manufacturing price (7), relative wages are:

$$\frac{w}{w^*} = \frac{\mu}{1 - \mu}. \quad (9)$$

The economy is therefore divided into a rich manufacturing North and a poor agricultural South. There is a Dutch disease flavor to this story. By having a comparative advantage in food, the South gets stuck in agricultural production, and by doing so gives up future productivity gains in manufacturing; see Matsuyama (1992) and Krugman (1987).

The central government now reduces regional inequality by limiting the relative wage in the rich region to  $\alpha$ , where  $1 \leq \alpha \leq \mu/(1 - \mu)$ ; the smaller  $\alpha$ , the greater the degree of redistribution. The value of  $\alpha$  is decided at the beginning of the first period, and lasts until the end of the second

period. In a two-period model—unlike in an infinite-horizon model—such a policy is time inconsistent: the rich region has no incentive to subsidize the poor region in the second period. This problem would disappear in an infinite-horizon model.<sup>3</sup>

Interregional redistribution is implemented by taxing manufacturing workers in the rich region, and subsidizing food workers in the poor region. The redistribution policy does not give anyone an incentive to switch sectors, so that production is unaffected. Given homothetic preferences, the relative manufacturing price does not change either. Only wages are affected by redistribution.

Since, in the first period, Northern taxes subsidize Southern workers, wages drop in the North and rise in the South:

$$w = p_M A - t \tag{10}$$

$$w^* = 1 + t^*, \tag{11}$$

where the tax  $t$  and the subsidy  $t^*$  are such that:

$$\frac{w}{w^*} = \alpha. \tag{12}$$

Assuming a balanced budget, we have:

$$t = t^*. \tag{13}$$

Using (7) and (10)–(13), we can derive wages, as a function of  $\alpha$ , in both regions:

$$w = \frac{1}{1 - \mu} \frac{\alpha}{1 + \alpha} \tag{14}$$

$$w^* = \frac{1}{1 - \mu} \frac{1}{1 + \alpha}. \tag{15}$$

This translates into the following utilities for North and South in period 1:

$$U_1(\alpha) = v\left(\frac{\alpha}{1 + \alpha} A^\mu\right) \tag{16}$$

$$U_1^*(\alpha) = v\left(\frac{1}{1 + \alpha} A^\mu\right). \tag{17}$$

Not surprisingly, redistribution increases welfare in the South, and decreases welfare in the North.

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<sup>3</sup> Our working paper version (available on request) contains such a time-consistent infinite-horizon model.

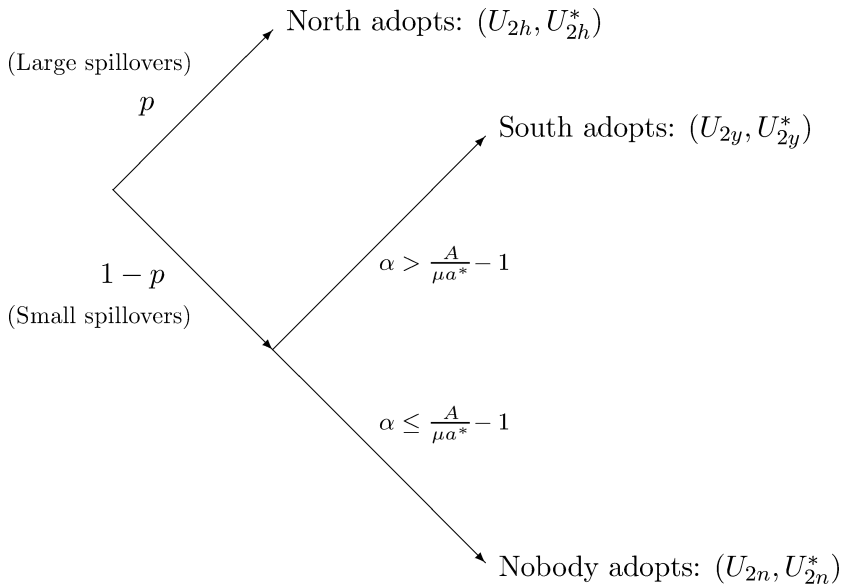
Higher wages make the South less attractive for new industries. Inter-regional transfers may thus contribute to persistent underdevelopment. In the next subsection, we develop this argument in detail.

### *Period 2*

In period 2 a new manufacturing technology is exogenously introduced. Although neither region has any direct experience with the new technology, the North benefits from learning spillovers from the old technology. These spillovers may be large or small, depending on the similarity between the two technologies.

As can be seen in Figure 1, with probability  $p$  spillovers are large, and the North's productivity in the new technology is high:  $a_h > A$ ; with probability  $1-p$  spillovers are small, and the North's productivity in the new technology is low:  $a_l < A$ . Since the South does not benefit from learning spillovers, its productivity in the new technology in either case is below that of the North:  $a^* < a_l < a_h$ .

Once a region adopts the new technology, it starts accumulating experience and moves up the learning curve of the new technology. Productivity increases until it reaches a maximum  $\hat{A} > A$ , at which point learning is exhausted. For simplicity, we assume that learning occurs instantaneously.



*Fig. 1.* Adoption of new technology



This allows us to ignore the transition phase, so that the model boils down to a simple discrete two-period problem.

The effect of the new technology on the development of the North and the South depends on where the new technology locates. In what follows we distinguish between three cases: the North adopts the new technology; the South adopts the new technology; or neither region adopts the new technology.

*Case 1: The North Adopts the New Technology.* In the case of large spillovers, which occurs with probability  $p$ , the North adopts the new technology (since  $a_h > A$ ), whereas the South remains stuck in agriculture.<sup>4</sup> The specialization pattern has not changed; the only difference is that the North now uses a superior manufacturing technology. Given that learning occurs instantaneously, period 2 utilities for North and South are, by analogy with (16) and (17):

$$U_{2h}(\alpha) = v\left(\frac{\alpha}{1+\alpha}\widehat{A}^\mu\right) \quad (18)$$

$$U_{2h}^*(\alpha) = v\left(\frac{1}{1+\alpha}\widehat{A}^\mu\right). \quad (19)$$

Spillovers have allowed the North to attract the new technology in spite of its higher wages. The North reinforces its dominant position, whereas the South remains trapped in underdevelopment.

*Case 2: The South Adopts the New Technology.* In the case of small spillovers, which occurs with probability  $1-p$ , the North does not adopt the new technology (since  $a_l < A$ ). The South, however, does adopt the new technology if its workers can earn higher wages by switching from food to the new technology. As can be seen in Figure 1, this happens if  $p_M a^* > [1/(1-\mu)][1/(1+\alpha)]$ , or, equivalently, if redistribution is relatively limited:

$$\alpha > \frac{A}{\mu a^*} - 1. \quad (20)$$

Once the South adopts the new technology, it starts moving up its learning curve. Since the new technology is superior to the old technology, the South overtakes the North and the specialization pattern is reversed: the South becomes rich and industrialized, and the North poor and agricultural.<sup>5</sup>

<sup>4</sup> Of course, the South may also adopt the new technology if, by doing so, its workers earn higher wages, i.e., if  $\mu a^*/a_h > 1/(1+\alpha)$ . We assume this condition is never satisfied.

<sup>5</sup> We assume the condition for full specialization is satisfied.

Assuming learning occurs instantaneously, period 2 utilities in North and South are:<sup>6</sup>

$$U_{2y}(\alpha) = v\left(\frac{1}{1+\alpha}\widehat{A}^\mu\right) \quad (21)$$

$$U_{2y}^*(\alpha) = v\left(\frac{\alpha}{1+\alpha}\widehat{A}^\mu\right). \quad (22)$$

The new technology has located in the low-wage South, thereby helping that region to take off and leapfrog. This situation fits the example of Belgium where, during the 1960s, the rural north overtook the industrialized south. As the traditional heavy industries in southern Belgium declined, new activities, such as plastics and lighter metals, located in the north, attracted by its low wages. This eventually led to leapfrogging: whereas in 1950, GDP per capita in northern Belgium was still 14% lower than in the south, by 1990 it was 31% higher.

*Case 3: Neither Region Adopts the New Technology.* The third possibility consists of neither region adopting the new technology. As suggested by Figure 1, this occurs when spillovers are small and when redistribution is relatively high:

$$\alpha \leq \frac{A}{\mu a^*} - 1. \quad (23)$$

In this case, nothing changes; period 2 utilities in North and South coincide with period 1 utilities:<sup>7</sup>

$$U_{2n}(\alpha) = v\left(\frac{\alpha}{1+\alpha}A^\mu\right) \quad (24)$$

$$U_{2n}^*(\alpha) = v\left(\frac{1}{1+\alpha}A^\mu\right). \quad (25)$$

Whether the economy is in Case 2 or in Case 3 depends on whether condition (20) or (23) is satisfied. The degree of redistribution therefore determines whether the South has a chance to develop and leapfrog. If redistribution is too high (Case 3), the South is sure to remain backward; at lower levels of redistribution (Case 2), the South may take off. This allows us to define the following two subsets of  $\alpha$ :

<sup>6</sup> The subscript  $y$  stands for “yes, the South adopts”.

<sup>7</sup> The subscript  $n$  stands for “no, the South does not adopt”.

**Definition 1.** For a given  $\mu$ ,  $a^*$  and  $A$ , we define  $\Gamma$  as the set of  $\alpha$  for which the South never adopts the new technology (condition (23) holds), and we define  $\Gamma^c$  as the set of  $\alpha$  for which the South has a chance of adopting the new technology (condition (20) holds).

The effect of subsidies to food workers is straightforward: by raising wages in the South, subsidies make the region less attractive for new industries, thus leading to persistent underdevelopment. This suggests, for instance, that the European Union's income support system for farmers contributes to keeping backward agricultural regions poor.

Although technology adoption may be unprofitable from an individual's point of view, it may still be beneficial for a region. In such cases, government intervention may be called for. As an example, the North could subsidize the adoption of the new technology by its own workers. However, we do not consider this possibility for a number of reasons. First, our model may be viewed as a reduced form of a more realistic setup where many new technologies emerge, most of which flounder. In such an environment, subsidizing all new technologies may be too costly, whereas "picking winners" may be impossible due to informational limitations. Second, our focus is on Pareto-efficient interregional transfers. An instance of the North subsidizing its own workers to adopt the new technology does not fall into this class of policies.

### *Joining the Two Periods*

Let  $\beta$  be the common discount factor for both regions. The discounted sum of expected utility in the North depends on whether the South leapfrogs or not:

$$U_y(\alpha) = U_1(\alpha) + \beta[pU_{2h}(\alpha) + (1-p)U_{2y}(\alpha)] \quad (26)$$

$$U_n(\alpha) = U_1(\alpha) + \beta[pU_{2h}(\alpha) + (1-p)U_{2n}(\alpha)]. \quad (27)$$

Similarly, the discounted sum of expected utility in the South depends on whether it takes off or not:

$$U_y^*(\alpha) = U_1^*(\alpha) + \beta[pU_{2h}^*(\alpha) + (1-p)U_{2y}^*(\alpha)] \quad (28)$$

$$U_n^*(\alpha) = U_1^*(\alpha) + \beta[pU_{2h}^*(\alpha) + (1-p)U_{2n}^*(\alpha)]. \quad (29)$$

Summarizing, total expected utility in North and South can be written as:

$$U(\alpha) = \begin{cases} U_y(\alpha) & \text{if } \alpha \in \Gamma^c \\ U_n(\alpha) & \text{if } \alpha \in \Gamma \end{cases} \quad (30)$$

$$U^*(\alpha) = \begin{cases} U_y^*(\alpha) & \text{if } \alpha \in \Gamma^c \\ U_n^*(\alpha) & \text{if } \alpha \in \Gamma. \end{cases} \quad (31)$$

### III. Rational Underdevelopment

High enough transfers ensure that the South remains backward. We now want to show that such transfers may be Pareto superior to any other level of transfers where the South takes off. In other words, the South chooses to remain poor, and the North chooses to continue paying transfers. This is what we call rational underdevelopment.

**Definition 2.** *A redistribution policy  $\alpha \in \Gamma$  leads to rational underdevelopment if  $U(\alpha) \geq U(\alpha')$  and  $U^*(\alpha) \geq U^*(\alpha')$  for all  $\alpha' \in \Gamma^c$ . We denote by  $\Gamma^{RU}$  the set of such redistribution policies.*

Our goal here is to show that the set of redistribution policies leading to rational underdevelopment is not empty. By giving transfers, the North keeps the South backward, thus making sure it remains in the lead. The South, on the other hand, prefers the certainty of transfers—and relative backwardness—to the uncertainty of taking off. In addition to risk sharing, transfers also lead to consumption smoothing: the North gives up income in the first period for higher expected income in the second period, and the opposite occurs in the South. Although both motives cannot be neatly separated in our particular setup, arguably risk sharing is the dominant factor. In the absence of uncertainty, consumption smoothing would most likely occur through private capital markets. Furthermore, it is straightforward to show that our results would go through in the absence of consumption smoothing. We return to this issue in the numerical section.

Figure 2 gives a graphical example of rational underdevelopment. It shows utility as a function of redistribution. For high levels of redistribution ( $\alpha \in \Gamma$ ) the South never adopts the new technology. In that case the North wants to minimize redistribution, whereas the South wants to maximize redistribution; this shows up in the North's utility increasing in  $\alpha$  and the South's utility decreasing in  $\alpha$ . For low levels of redistribution ( $\alpha \in \Gamma^c$ ) both the North and the South have a chance of attracting the new industry. At the cut-off point between  $\Gamma$  and  $\Gamma^c$ , the utility functions undergo a discrete jump. Since the North prefers that the South not adopt the new technology,<sup>8</sup> the North's utility at the cut-off point between  $\Gamma$  and  $\Gamma^c$  is such that  $U_n(\alpha) > U_y(\alpha)$ . By analogy, the opposite occurs in the South.

<sup>8</sup> We are thus assuming that the productivity increase from the new technology is not too large; Condition 2 discusses this point in further detail.

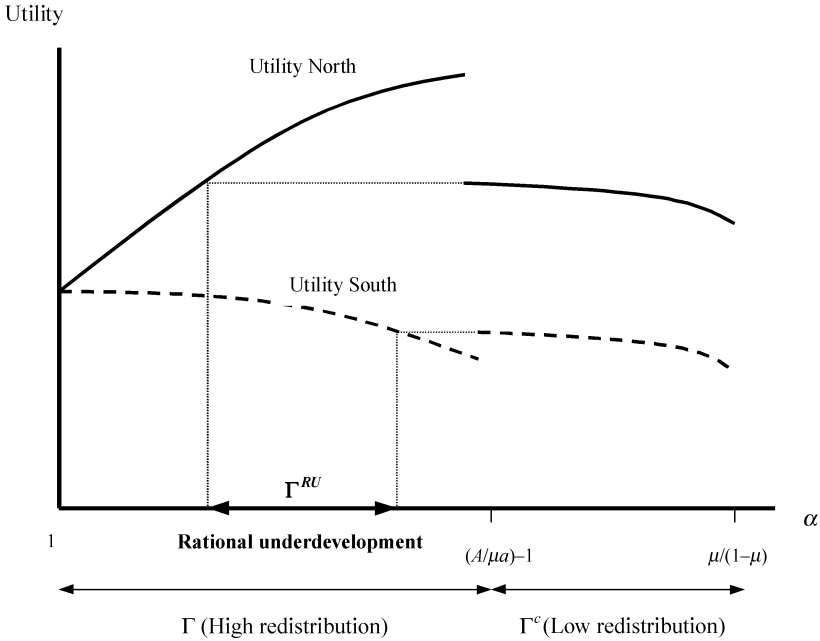


Fig. 2. Example of rational underdevelopment

Rational underdevelopment occurs if there are levels of redistribution where the South is sure to remain backward, and which are Pareto superior to any other level of redistribution where the South has a chance of taking off. This corresponds to set  $\Gamma^{RU} \subset \Gamma$  in Figure 2: for all  $\alpha \in \Gamma^{RU}$ , utilities in the North and South are superior to utilities associated with any  $\alpha \in \Gamma^c$ .

Before analytically proving that rational underdevelopment may exist, we add some more structure on the problem. First, for the North to have any interest in paying transfers, it should be uncertain whether it will attract the new technology, and it should care about this second-period uncertainty:

*Condition 1.*  $p < 1$  and  $\beta > 0$ .

Second, if the productivity gain from the new technology is too large, the North may experience welfare gains from the South switching to the new technology; although the North would lose out on the new technology, it would be more than compensated by the decline in the relative manufacturing price. Rational underdevelopment would not occur because the North would prefer that the South adopt the new technology to a situation where no one adopts the new technology. To avoid this case, we put an upper limit on the productivity gain of the new technology:

*Condition 2.*  $(\widehat{A}/A)^\mu < \mu/(1-\mu)$ .

Third, focusing on the range of redistribution policies for which neither region adopts the new technology, the North's maximum level of redistribution should be higher than the South's minimum level of redistribution. The North's maximum level of redistribution  $\widehat{\alpha}$  is the level above which it prefers zero transfers; the South's minimum level of redistribution  $\widehat{\alpha}^*$  is the level below which it prefers zero transfers. Therefore,  $\widehat{\alpha}$  is the solution to  $U_n(\widehat{\alpha}) = U_y(\mu/(1-\mu))$  and  $\widehat{\alpha}^*$  is the solution to  $U_n^*(\widehat{\alpha}^*) = U_y^*(\mu/(1-\mu))$ .<sup>9</sup> This gives us the third condition:

*Condition 3.*  $\widehat{\alpha} < \widehat{\alpha}^*$ .

We do not provide the complete set of parameters which satisfy Condition 3, because that set depends in a non-trivial way on  $p$ ,  $\mu$ ,  $A$ ,  $A^*$ ,  $\beta$  and the specific utility function  $v$ .

It is, however, easy to see that higher risk aversion increases the demand for transfers in both regions, and thus favors Condition 3. To illustrate this point, compare the cases of no risk aversion and very high risk aversion. In the case of no risk aversion, transfers never increase the total utility of the economy, so that they cannot make both regions better off. One region's gain is always the other region's loss, so that Condition 3 is never satisfied. As risk aversion goes up, the possibility of a "bad" outcome starts to weigh more heavily in a region's utility: the North becomes increasingly concerned about falling behind, and the South becomes increasingly worried about being backward. Since transfers mitigate the "bad" outcome in both regions, at high levels of risk aversion it becomes easier to find a set of transfer policies which are welfare improving for both North and South.

We are now ready to prove analytically that, under certain conditions, rational underdevelopment exists:

**Theorem 1.** *Let Conditions 1, 2 and 3 hold. Let all parameters but  $a^*$  be fixed. Then, there exists  $k \leq A$ , such that for all  $a^* \leq k$  we have rational underdevelopment, i.e., the set  $\Gamma^{RU}$  is not empty.*

*Proof:* See the Appendix.

Summing up, rational underdevelopment tends to occur if productivity gains deriving from the new technology are modest (Condition 2); risk aversion

<sup>9</sup> If  $U_n(\alpha) > U_y(\mu/(1-\mu))$  for all  $\alpha \in \Gamma$ , we take  $\widehat{\alpha} = 1$ ; and if  $U_n^*(\alpha) > U_y^*(\mu/(1-\mu))$  for all  $\alpha \in \Gamma$ , we take  $\widehat{\alpha}^{ast} = A/(\mu a^*) - 1$ . Likewise, if  $U_n(\alpha) < U_y(\mu/(1-\mu))$  for all  $\alpha \in \Gamma$ , we take  $\widehat{\alpha} = A/(\mu a^*) - 1$ ; and if  $U_n^*(\alpha) < U_y^*(\mu/(1-\mu))$  for all  $\alpha \in \Gamma$ , we take  $\widehat{\alpha}^* = 1$ . Since  $U_n(\alpha)$  is strictly increasing and  $U_n^*(\alpha)$  is strictly decreasing,  $\widehat{\alpha}$  and  $\widehat{\alpha}^*$  are well defined.

is high (Condition 3); and the initial productivity of the new technology in the South is low (Theorem 1). All these conditions have already been discussed, except the last one, which has an easy interpretation: for a low value of  $a^*$ , the South only adopts the new technology if its wages are also low. In that case a modest transfer scheme may be enough to keep the South from attracting the new technology.

A relevant question is whether and how our results depend on the assumption that technological change takes place only once. As mentioned above, it is straightforward to generalize our result to an infinite-horizon overlapping-generations model. This would seem to be the right setup if the focus is on technological breakthroughs, which occur only “once every generation”. If, instead, we were to think of an infinite-horizon representative-agent model with technological change every period, the case for rational underdevelopment would weaken.

Before continuing, note that our example of wage subsidies might be regarded as too restrictive. However, in a more realistic setup with an elastic labor supply and the possibility of unemployment, many of the standard regional policy instruments would have the same effect. Regardless of whether we are considering publicly provided goods, unemployment benefits or public employment, all of these policies either reduce the labor supply or lead to an increase in the reservation wage; see Desmet (2002). Either way, the equilibrium wage in the backward region rises, without being accompanied by a productivity increase, so that the possibility of rational underdevelopment remains. The same would be true if (lump-sum) transfers were paid to all workers in the South, including those adopting the new technology. The income effect would shift the labor supply schedule leftward, thereby raising the relative price of food and pushing up wages.

Of course, there are other regional policies, such as subsidies to infrastructure or capital, which would not keep the South backward. However, in such cases it is not clear what the North would stand to gain. Another policy alternative could be for the North to tax its own workers who use the old technology, thus ensuring that they adopt the new technology. However, such a policy would be clearly detrimental to the South. As already mentioned, in this paper we limit our focus to Pareto-efficient interregional transfers. In addition, the kinds of redistributive policies we have in mind—wage subsidies, unemployment benefits and public employment—share another feature: they are non-discriminatory. In the specific case of wage subsidies, they go from rich to poor, independently of which region is rich or poor. This seems a natural assumption in a setting where we focus on regions *within* countries, rather than on different countries.<sup>10</sup>

<sup>10</sup> Beyond the realm of regional policy, it would be interesting to explore whether the case of rich countries subsidizing imports from poor countries would lead to a similar outcome.

#### IV. Some Numerical Illustrations

Consider the following baseline case. Take the CRRA utility function  $v = x^{1-\rho}/(1-\rho)$ . Following Mehra and Prescott (1985), we restrict values for  $\rho$  to be less than 10;<sup>11</sup> as a starting point we take  $\rho = 5$ . We choose GDP per capita in the rich region to be 50% higher than in the poor region, implying  $\mu = 0.6$ . This is reasonable based on data for 1996: in Italy GDP per capita in the north was 79% higher than in the south; in Spain, the east had an advantage of 53% over the south; and in Belgium, the difference was 29% between the north and the south; cf. Eurostat (2000). U.S. figures from the Bureau of Economic Analysis are similar: in 1998 GDP per capita in Massachusetts was 72% above that of Mississippi.

We normalize  $A = 1$  and set  $\hat{A} = 1.1$ . Comparing the South's adoption of the new technology with the North's, these figures imply an annual real productivity growth rate over a period of 25 years which is on average 1.6 percentage points higher in the South. This is roughly in line with differences in total factor productivity (TFP) growth rates across countries; see Young (1995). For the initial productivity of the new technology in the South we take  $a^* = 0.7$ ; this implies an annual productivity increase of around 2% if the South adopts the new technology. Following standard practice, we assume an annual real interest rate of 4%, which leads to an annual discount factor of around 0.96. If we think of new technologies as arising once every 25 years, this gives a value for  $\beta$  of 0.375. Finally, for want of a specific prior, we set the probability of the North adopting the new technology at  $p = 0.5$ .

Column (6) in Table 1 gives the set of redistribution policies  $\Gamma^{RU}$  consistent with rational underdevelopment. In the baseline case, rational underdevelopment occurs for transfers that reduce the North's relative income from 1.5 to a level ranging from 1.218 to 1.312. This corresponds to a 38% to 56% decrease in regional inequality. This reduction in inequality is substantial, though not unusual. Estimates for Canadian provinces in the 1980s find a figure of 44%; see Bayoumi and Masson (1995).<sup>12</sup> The two extremes of our range of redistribution policies have an easy interpretation: 1.218 corresponds to the maximum level of redistribution acceptable to the North and 1.312 corresponds to the minimum level of redistribution acceptable to the South. Column (7) in Table 1 gives the tax rates in the North required to finance redistribution: to limit relative income to 1.218, we would need a tax rate of 8.5% in the North; to limit relative income to 1.312, that tax rate would drop to 5.4%.

<sup>11</sup> Kandel and Stambaugh (1991) claim that larger values of  $\rho$  should not be ruled out. See Campbell (1999) for a summary of the empirical literature on the coefficient of risk aversion.

<sup>12</sup> This is an upper bound.



**Table 1.** Rational underdevelopment for different parameter values

(1) Risk aversion $\rho$	(2) Discount factor $\beta$	(3) New technology $\hat{A}$	(4) North adopts $p$	(5) Productivity South $a^*$	(6) Rational underdevelopment $\Gamma^{RU}[\alpha_1, \alpha_2]$	(7) Tax rate North $[t/w(\alpha_1), t/w(\alpha_2)]$
(1) <i>Baseline case</i>						
5	0.375	1.10	0.5	0.7	<b>1.218, 1.312</b>	0.085, 0.054
(2) <i>Risk aversion</i>						
<b>9</b>	0.375	1.10	0.5	0.7	<b>1.128, 1.338</b>	0.117, 0.046
<b>3</b>	0.375	1.10	0.5	0.7	<b>1.284, 1.292</b>	0.063, 0.061
<b>2</b>	0.375	1.10	0.5	0.7	—	—
(3) <i>Discount factor</i>						
5	<b>0.3</b>	1.10	0.5	0.7	<b>1.251, 1.324</b>	0.074, 0.050
5	<b>0.4</b>	1.10	0.5	0.7	<b>1.208, 1.309</b>	0.088, 0.055
(4) <i>Productivity of new technology</i>						
5	0.375	<b>1.2</b>	0.5	0.7	<b>1.269, 1.307</b>	0.068, 0.056
5	0.375	<b>1.4</b>	0.5	0.7	—	—
(5) <i>Probability of North adopting</i>						
5	0.375	1.10	<b>0.6</b>	0.7	<b>1.251, 1.327</b>	0.071, 0.050
5	0.375	1.10	<b>0.4</b>	0.7	<b>1.181, 1.299</b>	0.097, 0.058
(6) <i>Initial productivity in South</i>						
5	0.375	1.10	0.5	<b>0.67</b>	<b>1.218, 1.411</b>	0.085, 0.025
5	0.375	1.10	0.5	<b>0.73</b>	<b>1.218, 1.224</b>	0.085, 0.083

Transfers improve welfare for different reasons. We now analyze the relative merit of these different motives for our benchmark case. First, transfers may provide insurance if it decreases the real income differential between the two states of nature in the second period. In the absence of transfers, that differential is 0.212 in both the North and the South. Taking the range of transfer levels consistent with rational underdevelopment, it drops to between 0.032 and 0.033 in the North, and to between 0.025 and 0.026 in the South. This implies that both regions benefit from risk sharing. Second, transfers can lead to consumption smoothing if the difference between real income in the first period and expected real income in the second period goes down. In the North, the absolute value of that difference drops from 0.071 to a range between 0.016 and 0.017. In the South, it drops from 0.129 to a range between 0.014 and 0.015. As a result, there is greater consumption smoothing in both regions. Third, transfers may increase the discounted sum of expected real income in one of the two regions. Here, the South gains (with an increase from 0.598 to a range between 0.599 and 0.625), and the North loses (with a drop from 0.799 to a range between 0.761 and 0.787).

Although three forces are at the origin of the welfare gains from transfers, arguably risk sharing is more important than the others. On the one hand, if

consumption smoothing were the main force, it is likely that private capital markets would solve the issue. Moreover, our results go through in a world without consumption smoothing. To see this, consider a simplified one-period version of our model. At the beginning of the period, the North and the South decide on the level of redistribution  $\alpha$ . Using the same parameter values as in our benchmark case, it can be shown that we still get rational underdevelopment. On the other hand, if transfers increase the real expected income of one region, it must come at the expense of the other. Since consumption smoothing is not needed, and both regions cannot benefit from higher expected income, risk sharing emerges as an essential force. Of course, this does not imply that both regions are insuring themselves. For instance, it is possible that the North gets insurance from the South, in exchange for an increase in the South's expected real income.

As a robustness check, and to gain further insight into the role of the different parameters, we now look at some variations of the baseline case. As expected, higher risk aversion increases the range of redistribution policies consistent with rational underdevelopment. Changing the discount factor has contrary effects in North and South. A lower discount rate increases the relative importance of the first period, so that the North wants less redistribution (since it is worried about insuring itself in the second period) and the South wants more redistribution (since it is the poor region in the first period).

Greater technological progress makes rational underdevelopment less likely. Rational underdevelopment occurs when the South foregoes the chance of adopting the new technology in exchange for transfers. This stance becomes more costly for the South if the productivity gain from the new technology is large. As suggested above by Condition 2, in that case the North would also become less likely to underwrite Southern backwardness: if productivity gains are substantial, the North actually gains from the South adopting the new technology.

Not surprisingly, varying the probability that the new technology will locate in the North has an asymmetric effect on both regions. As it becomes more likely for the North to adopt the new technology, the South wants more insurance, and the North wants less. Finally, increasing the initial productivity of the new technology in the South limits the possibility of rational underdevelopment; it now takes larger transfers from the North to convince Southern workers not to switch to the new technology.

## **V. Concluding Remarks**

In this paper we have proposed a model that explains rational underdevelopment. Fiscal transfers raise wages in the backward region, thus reducing its chances to attract new technologies and take off. With high enough

transfers, the poor region is sure to remain backward. If this situation is stable, we have rational underdevelopment: the leading region pays transfers to ensure that it remains in the lead, and the lagging region accepts these transfers because it might not benefit from the new technology.

Although we have focused on the specific case of wage subsidies, we have argued that our result is much more general. Public employment, lump-sum transfers and unemployment benefits would all lead to similar outcomes. Of course, there are other policy instruments more likely to benefit backward regions. The European Union's structural funds, which subsidize infrastructure and human capital, might be an example. However, our model suggests that such transfers may be unsustainable, because it is unclear what the richer regions gain from such an arrangement.

**Appendix: Proof of Theorem 1**

Let  $\Omega$  be the set of possible redistribution schemes, i.e.,  $\Omega = [1, \mu/(1 - \mu)]$ . In the second period the South adopts the new technology if

$$\alpha > \frac{A}{\mu a^*} - 1.$$

To simplify the notation we drop “\*” throughout this appendix and write  $a$ . Let  $\alpha(a) \equiv A/(\mu a) - 1$ . Thus the function  $\alpha(a)$  gives the level of redistribution that makes the South indifferent between adopting the new technology and continuing to produce exclusively food. The set of redistributive policies for which the South does not adopt the new technology is:

$$\Gamma(a) \equiv \{\alpha \in \Omega : \alpha \leq \alpha(a)\} = [1, \alpha(a)].$$

Sometimes we just write  $\Gamma$ . Let  $\Gamma^c(a) \equiv \Omega/\Gamma(a)$ , i.e.,  $\Gamma^c(a)$  is the set of  $\alpha$  for which the South adopts the technology. This set is also an interval of the form  $] \alpha(a), \mu/(1 - \mu) ]$ . Sometimes we write it as  $\Gamma^c$ . Recall that the expressions for the expected utilities were given by

$$U(\alpha) = \begin{cases} U_y(\alpha) & \text{if } \alpha \in \Gamma^c \\ U_n(\alpha) & \text{if } \alpha \in \Gamma \end{cases}$$

$$U^*(\alpha) = \begin{cases} U_y^*(\alpha) & \text{if } \alpha \in \Gamma^c \\ U_n^*(\alpha) & \text{if } \alpha \in \Gamma. \end{cases}$$

These functions are continuous everywhere in  $\Omega$  except possibly at  $\alpha(a)$  (see Figure 2). The strategy of the proof consists in showing that we can generate a situation similar to that in Figure 2.

*Step 1.*  $U_n(\alpha)$  is strictly increasing and  $U_n^*(\alpha)$  is strictly decreasing.  $U_n(\alpha)$  is given by

$$v\left(\frac{\alpha}{1 + \alpha} A^\mu\right) + \beta \left[ pv\left(\frac{\alpha}{1 + \alpha} \widehat{A}^\mu\right) + (1 - p)v\left(\frac{\alpha}{1 + \alpha} A^\mu\right) \right],$$

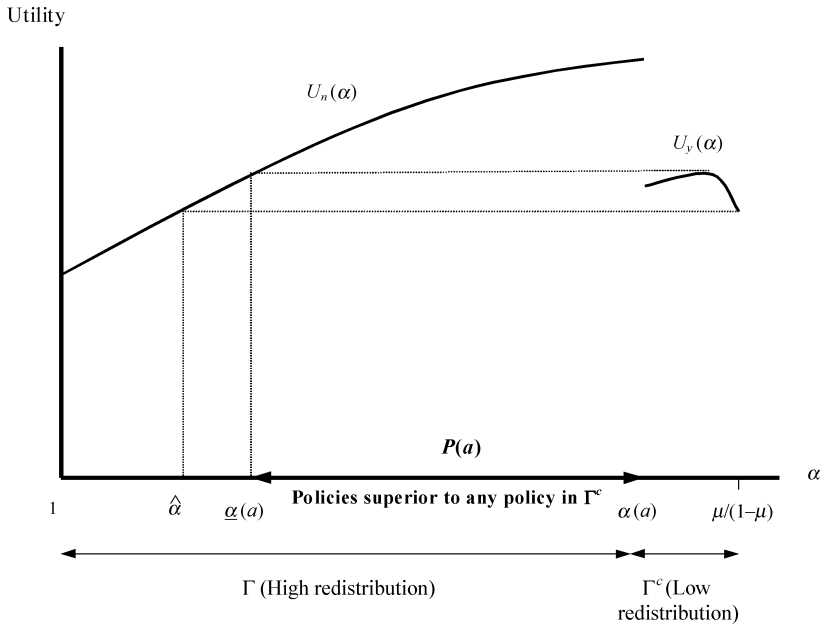


Fig. A1. Policies preferred by the North

which is, clearly, strictly increasing in  $\alpha$ .  $U_n^*(\alpha)$  is given by

$$v\left(\frac{1}{1+\alpha}A^\mu\right) + \beta\left[pv\left(\frac{1}{1+\alpha}\widehat{A}^\mu\right) + (1-p)v\left(\frac{1}{1+\alpha}A^\mu\right)\right],$$

which is, clearly, strictly decreasing in  $\alpha$ .

Step 2. We construct a set  $P \subset \Gamma$  of redistribution policies that are preferred by the North to any policy in  $\Gamma^c$  (see Figure A1).

- (i) For  $\bar{\alpha} \equiv A(1-\mu)/\mu$  we have  $\Gamma(\bar{\alpha}) = [1, (1-\mu)/\mu]$ , i.e., the new technology is never adopted.
- (ii) We have

$$U_n\left(\frac{\mu}{1-\mu}\right) = u(\mu A^\mu) + \beta[p u(\mu \widehat{A}^\mu) + (1-p)u(\mu A^\mu)]$$

and

$$U_y\left(\frac{\mu}{1-\mu}\right) = u(\mu A^\mu) + \beta[p u(\mu \widehat{A}^\mu) + (1-p)u((1-\mu)\widehat{A}^\mu)],$$

so that  $U_n(\mu/(1-\mu)) > U_y(\mu/(1-\mu))$  if  $p < 1$ ,  $\beta > 0$  and  $\mu/(1-\mu) > (\widehat{A}/A)^\mu$ . This corresponds to Conditions 1 and 2, so that  $U_n(\mu/(1-\mu)) > U_y(\mu/(1-\mu))$ .

- (iii) By the previous two points and by continuity of  $U_n, U_y$  and  $\alpha(a)$ , there exists  $\tilde{a} > \bar{a}$  close enough to  $\bar{a}$  such that  $U_n(\alpha(\tilde{a})) > U_y(\alpha)$  for all  $\alpha \in [\alpha(\tilde{a}), \mu/(1-\mu)]$ .
- (iv) Let  $z = \max_{\alpha \in [\alpha(\tilde{a}), \mu/(1-\mu)]} U_y(\alpha)$ . By continuity of  $U_y(\alpha)$  the value  $z$  is well defined. Let  $\underline{\alpha}(\tilde{a})$  be the solution to

$$z = U_n(\alpha)$$

and if  $z < U_n(\alpha)$  for all  $\alpha \in \Omega$ , we set  $\underline{\alpha}(\tilde{a}) = 1$ . Since  $U_n(\alpha)$  is strictly increasing  $\underline{\alpha}(\tilde{a})$  is well defined.

Let  $P(\tilde{a}) \equiv \{\alpha : \underline{\alpha}(\tilde{a}) \leq \alpha \leq \alpha(\tilde{a})\}$ . By construction  $P(\tilde{a}) \subset \Gamma(\tilde{a})$ . Moreover,  $P(\tilde{a})$  is non-empty. To see this, it suffices to show that  $\underline{\alpha}(\tilde{a}) < \alpha(\tilde{a})$ . This is immediate, given that  $U_n(\alpha)$  is strictly increasing and given that  $U_n(\alpha(\tilde{a})) > U_y(\alpha)$  for all  $\alpha \in [\alpha(\tilde{a}), \mu/(1-\mu)]$ . It is also clear that for any  $\alpha \in P(\tilde{a})$  we have  $U_n(\alpha) \geq U_y(\alpha')$  for all  $\alpha' \in \Gamma^c(\tilde{a})$ . Thus, the transfer schemes in  $P(a)$  are Pareto superior for the North to the transfers schemes for which the South adopts the new technology. Note that the North is (weakly) better off under  $\alpha \in P(\tilde{a})$  than under zero transfers, i.e., all the policies in  $P(\tilde{a})$  are also individually rational for the North.

Recall that  $\hat{\alpha}$  satisfies  $U_n(\hat{\alpha}) = U_y(\mu/(1-\mu))$ . It is not difficult to see that for  $a$  small enough, the value  $\alpha(a)$  approaches  $\mu/(1-\mu)$  and  $\underline{\alpha}(a)$  approaches  $\hat{\alpha}$  (see Figure A1), i.e.:

$$\lim_{a \rightarrow \left(\frac{A(1-\mu)}{\mu}\right)^+} \underline{\alpha}(a) = \hat{\alpha}$$

and

$$\lim_{a \rightarrow \left(\frac{A(1-\mu)}{\mu}\right)^+} \alpha(a) = \frac{\mu}{1-\mu}.$$

The idea is simple; when  $a$  approaches (from the right) its lowest possible value, the South almost never adopts the new technology and the set  $P(a)$  approaches the set of all  $\alpha$ 's such that  $U_n(\alpha) > U_y(\mu/(1-\mu))$ . The lower bound of this set is  $\hat{\alpha}$  and the upper bound is  $\mu/(1-\mu)$ . Given that  $\hat{\alpha} < \underline{\alpha}(\tilde{a})$  and  $\mu/(1-\mu) > \alpha(\tilde{a})$ , and given that  $P(\tilde{a})$  is non-empty, it is clear that for  $a$  small enough,  $P(a)$  is non-empty.

*Step 3.* We construct, in a parallel way to Step 2 for the North, a set  $P^* \subset \Gamma$  of redistribution policies that are preferred by the South to any policy in  $\Gamma^c$  (see Figure A2).

- (i) Condition 3 implies that  $U_n^*(1) > U_y^*(\mu/(1-\mu))$ . Step 1 showed that  $U_n^*(\alpha)$  is strictly decreasing in  $\alpha$ . Hence, and by continuity of  $U_n^*, U_y^*$  and  $\alpha(a)$ , there exists  $a' > \bar{a} \equiv A(1-\mu)/\mu$  close enough to  $\bar{a}$  such that  $U_n^*(1) > U_y^*(\alpha)$  for all  $\alpha \in [\alpha(a'), \mu/(1-\mu)]$ .
- (ii) Let  $z = \max_{\alpha \in [\alpha(a'), \mu/(1-\mu)]} U_y^*(\alpha)$ . By continuity of  $U_y^*(\alpha)$  the value  $z$  is well defined. Let  $\bar{\alpha}(a')$  be the solution to

$$z = U_n^*(\alpha).$$

Since  $U_n^*(\alpha(a')) < U_y^*(\alpha(a'))$ , since  $U_n^*(\alpha)$  is strictly decreasing, and since  $U_n^*(1) > z$ , we can conclude that  $\bar{\alpha}(a')$  is well defined.

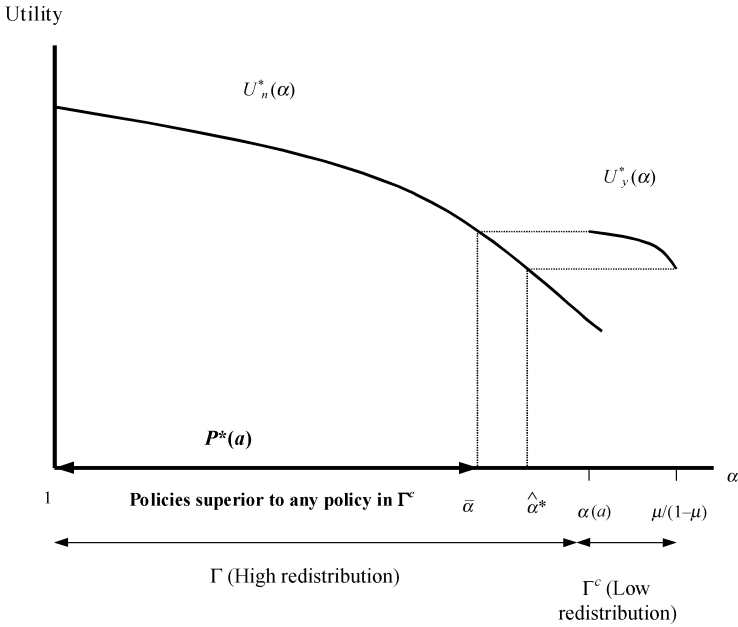


Fig. A2. Policies preferred by the South

Let  $P^*(a') \equiv \{\alpha : 1 \leq \alpha \leq \bar{\alpha}(a')\}$ . By construction  $P^*(a') \subseteq \Gamma(a')$ . Moreover,  $P^*(a')$  is non-empty. To see this, it suffices to show that  $\bar{\alpha}(a') < 1$ . This is immediate, given that  $z < U_n^*(1)$ . It is also clear that for any  $\alpha \in P^*(a')$  we have  $U_n^*(\alpha) \geq U_y^*(\alpha')$  for all  $\alpha' \in \Gamma^c(a')$ . Thus, the transfer schemes in  $P^*(a')$  are Pareto superior for the South to the transfers schemes for which the South adopts the new technology. Note that the South is (weakly) better off under  $\alpha \in P^*(a')$  than under zero transfers, i.e., all the policies in  $P^*(a')$  are also individually rational for the South. Recall that  $\hat{\alpha}^*$  satisfies  $U_n^*(\hat{\alpha}^*) = U_y^*(\mu/(1-\mu))$ . It is not difficult to see that for  $a$  small enough, the value  $\alpha(a)$  approaches  $\mu/(1-\mu)$  and  $\bar{\alpha}(a)$  approaches  $\hat{\alpha}^*$  (see Figure A2), i.e.:

$$\lim_{a \rightarrow \left(\frac{A(1-\mu)}{\mu}\right)^+} \bar{\alpha}(a) = \hat{\alpha}^*.$$

Given that  $\hat{\alpha}^* > \bar{\alpha}(a')$  and given that  $P^*(a')$  is non-empty, it is clear that for  $a$  small enough the set  $P^*(a)$  is non-empty.

*Step 4.* We want to show that for  $a$  small enough the set  $R(a) \equiv P(a) \cap P^*(a)$  is not empty. Recall that  $P(a)$  is given by the interval  $[\underline{\alpha}(a), \alpha(a)]$  and  $P^*(a)$  is given by the interval  $[1, \bar{\alpha}(a)]$ , and for  $a$  small enough these intervals are not empty: We showed that  $\lim_{a \rightarrow (A(1-\mu)/\mu)^+} \underline{\alpha}(a) = \hat{\alpha}$  and  $\lim_{a \rightarrow (A(1-\mu)/\mu)^+} \bar{\alpha}(a) = \hat{\alpha}^*$ . Thus, for  $a$  small enough,  $R(a)$  is not empty if  $\hat{\alpha} < \hat{\alpha}^*$ , and this inequality is just Condition 3. Since  $R(a) \subseteq \Gamma^{RU}(a)$  we have that, for  $a$  small enough,  $\Gamma^{RU}(a)$  is not empty. This concludes the proof.

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