Measuring Aggregate Productivity Growth Using Plant-level Data

by

Amil Petrin
University of Minnesota, Twin Cities
National Bureau of Economic Research
and
James Levinsohn
University of Michigan
National Bureau of Economic Research

May 29, 2008

Abstract. We define Petrin-Levinsohn (PL) aggregate productivity growth as the change in aggregated final demand minus the change in the aggregated cost of primary inputs. It is an indicator of the change in potential aggregate consumption holding total primary input use constant. We show how to aggregate plant-level data to PL, and how to use plant-level data to decompose PL into technical efficiency and reallocation components. We confront the "non-neoclassical" features that impact plant-level data, including related factors like plant-level heterogeneity, the entry and exit of goods, fixed and sunk costs, markups, returns to scale, adjustment costs like hiring, firing and search costs, gestation lags, and sub-optimal behavior of plants. There are well-known estimation techniques available for both the reallocation and real growth components of PL. While the assumptions necessary for PL to equal welfare are strong, many well-known theoretical models write down welfare functions that are special cases of it measures the change in potential consumption. We compare PL to several variants of a widely used alternative definition of aggregate productivity growth proposed originally in Bailey, Hulten, and Campbell (1992). While these indexes have decompositions into technical efficiency and reallocation terms that are similar in spirit, we show economic theory suggests the BHC will depart from the PL on both the aggregate technical efficiency term and the reallocation term. Panel data for manufacturing industries from Chile and Colombia show that these two measures can differ significantly, as do several results from other studies.

Measuring Aggregate Productivity Growth Using Plant-level Data

Amil Petrin
University of Minnesota, Twin Cities
National Bureau of Economic Research
and
James Levinsohn
University of Michigan
National Bureau of Economic Research

May 29, 2008

1. Introduction

Definition and measurement of aggregate productivity growth is at the heart of a wide range of fields in economics. In this paper we use a continuous time setting and define Petrin-Levinsohn (PL) aggregate productivity growth as the change in the value of aggregate final demand minus the change in cost of inputs. This definition is in the spirit of a long history of productivity growth measures that have been calculated using aggregate data. Intuitively, it is an indicator of the change in potential consumption holding primary input use constant.

Our results extend Hulten (1978) and Basu and Fernald (2002). Hulten (1978) shows how to aggregate to PL with sector-level data in a neoclassical setting. Basu and Fernald (2002) use Hall (1990) to extend Hulten (1978) to a setting with markups. They also show that existence of markups means that PL can increase when inputs are reallocated from plants with low markups to plants with high markups.

Our contribution is to complete the extension to plant-level data. We show how to aggregate plant-level data to PL, and how to use plant-level data to decompose PL into several terms, including a term that aggregates changes in plant-level technical efficiency, and several more terms related to the reallocation of inputs across plants. The extension requires us to confront the "non-neoclassical" features that impact plant-level data, including related factors like plant-level

This paper grew out of initial work in "When Industries Become More Productive, Do Firms?: Investigating Productivity Dynamics" (NBER Working Paper 6893), and appeared in an earlier form as "On the Micro-Foundations of Productivity Growth." We are grateful to the Russell Sage Foundation and the University of Chicago GSB for support and for helpful discussions from Bert Balk, Susanto Basu, Eric Bartelsman, Jeff Campbell, Steve Davis, Erwin Diewert, John Fernald, John Haltiwanger, Charles Hulten, Mitsukuni Nishida, Wendy Petropoulos, Mark Roberts, Johannes Van Biesebroeck, Alwyn Young, the NBER Productivity meetings, the Chicago Applied Micro Lunch, the Society for Economic Dynamics and the Econometric Society Meetings.

heterogeneity, the entry and exit of goods, fixed and sunk costs, markups, returns to scale, adjustment costs like hiring, firing and search costs, gestation lags, and sub-optimal behavior of plants.[1]

Two attractive features of PL relate to its empirical measurement and its interpretation. On empirical measurement applied researchers have already developed several techniques to estimate the components of the aggregate technical efficiency term and the aggregate reallocation term.[2] On interpretation, while the assumptions necessary for our indicator of potential consumption to equal welfare are strong, many theoretical models of growth write down welfare functions that are special cases of PL, including several of the models cited in footnote 1.

We compare PL to several variants of the widely used indexes proposed in Bailey et al. (1992), including those in Olley and Pakes (1996), and Foster, Haltiwanger, and Krizan (2001). While these indexes have decompositions into technical efficiency and reallocation terms that are similar in spirit, we show economic theory suggests these BHC variants will depart from the PL measure on both dimensions.

The starkest difference between PL and BHC is on the measure of growth arising from reallocation. PL weights input movements using differences in the gaps between marginal revenue products and input prices. BHC weights input movements using differences in technical efficiency across plants. In equilibrium plants choose input levels to equate expected marginal revenue with expected cost of the input, regardless of their level of technical efficiency. Thus the BHC measure uses none of the information on the distribution of gaps in its assessment of growth arising from reallocation. We provide a simple Hotelling line model with markups and efficiency differences that clearly illustrates the problems with BHC in fuller detail.

Using panel data for manufacturing in Chile and Colombia, we show that these two measures differ significantly in their assessment of aggregate productivity growth. Together, our theoretical and empirical findings are consistent with previously reported BHC-type reallocation results which often exhibit volatile behavior relative to value added. They are consistent with results from the model in Lentz and Mortensen (2007), who show that the BHC reallocation term will always

[1] See, for example, Hopenhayn and Rogerson (1993), Petrin (2002), Goolsbee and Petrin (2004), Basu and Fernald (2002), Melitz (2003), Ericson and Pakes (1995), Aghion and Howitt (1992), Benhabib and Rustichini (1991), Berry and Tamer (2006), Caballero and Hammour (1994), Campbell (1998), Bentolila and Bertola (1990), Mortensen and Pissarides (1994), Lentz and Mortensen (2007), Bresnahan and Reiss (1991), Hsieh and Klenow (2007), and Restuccia and Rogerson (2007).

[2] There is an enormous literature on estimating plant-level technical efficiency and a growing literature on estimating the difference between marginal revenue products and input prices at the plant-level (see e.g. Petrin and Sivadasan (2006)).

equal zero in steady state even though all increases in consumption arise from the reallocation of inputs from low marginal revenue product firms to high marginal revenue product firms. They are consistent with results from Bartelsman, Haltiwanger, and Scarpetta (2006), who simulate a model with distortions to capital. For a distortion that lowers aggregate consumption by almost 50% the Olley-Pakes (OP) aggregate productivity growth measure is virtually unchanged, as OP technical efficiency term increases by 0.1% and the OP reallocation term decreases by 2.3%. In both Lentz and Mortensen (2007) and Bartelsman et al. (2006), our proposed measure PL exactly equals the change in aggregate consumption, as it must by construction.

We develop the PL measure and decomposition in Section 2. In Section 3, we compare the BHC-variants directly to PL. Section 4 covers data and estimation and Section 5 contains results. Section 6 concludes.

2. Theory

Let i index the N plants in the economy, P_i equal i's output price and Q_i equal to i's output. The production technology is given by $Q_i = Q^i(X^i, M^i, \omega_i)$, where $(X^i = X_{i1}, \ldots, X_{iK})$ and $(M^i = M^i_1, \ldots, M^i_N)$ with X_{ik} the amount of the kth primary input used in production at plant i, and M^i_j the amount of j's output used as an input in production of i. We introduce a new term, F_i, to reflect fixed and sunk costs at plant i not elsewhere reflected in expenditures. We then write the total amount of output from plant i that goes to final demand as Y_i

$$Y_i = Q_i - \sum_j M^j_i - F_i,$$

where $\sum_j M^j_i$ is the total amount of i's output that serves as intermediate input, and $dY_i = dQ_i - \sum_j dM^j_i - dF_i$. The fixed and sunk costs F_i are deducted directly from output, as is customarily done.[3] This last term is one of the main differences between our approach and what others have done in the past.

We define Petrin-Levinsohn (PL) aggregate productivity growth as the change in aggregate final demand minus the change in aggregate costs:

$$PL \equiv \sum_i P_i dY_i - \sum_i \sum_k W_{ik} dX_{ik}, \tag{1}$$

where W_{ik} is the marginal cost of kth primary input. The change in aggregate value added $\sum_i P_i dY_i$ is equal to the change aggregate final demand, and $\sum_i \sum_k W_{ik} dX_{ik}$ reflects changes in aggregate costs. Our focus is on aggregating up from the plant-level. We discuss (1) and derive its decomposition, starting with the new term in final demand.

[3] This requires fixed and sunk costs to be normalized to the output price, so actual costs $\tilde{F}_i = P_i F_i$, or $F_i = \frac{\tilde{F}_i}{P_i}$.

Fixed and Sunk Costs

A general formulation for F_i is

$$F_i(t) = \sum_k F_{ik}(t) + \sum_j F_{ij}(t),$$

where the use of any primary or intermediate input at plant i may at time t result in a fixed or sunk cost being incurred. The exact formulation for F_i will depend on the details of the situation as the role of F_i varies across different models of growth.

In creative destruction/vintage capital models F_i reflects the sunk costs associated with developing the new vintages. These can be one-time entry costs as in Bresnahan and Reiss (1991), Caballero and Hammour (1994), Aghion and Howitt (1994), Sweeting (2006), or Berry and Tamer (2006). They can be continually paid flow costs like research and development that lead to innovations at random times, which lead to jumps in aggregate consumption (see Aghion and Howitt (1992) and Lentz and Mortensen (2007)). Ericson and Pakes (1995) have both entry and development costs as different components of F_i.

In search cost and hiring and firing cost papers, F_i can reflect the costs of finding and training a new employee, and the severance payments and potential legal costs associated with firing employees, as in Mortensen and Pissarides (1994), Caballero and Hammour (1996), and Petrin and Sivadasan (2006).

F_i does not include the costs already accounted for in $\sum_{ik} W_{ik} dX_{ik}$. For example, if current labor work more hours to help train new labor, then that would be reflected in an increase in payments to labor inputs via $W_{ik} dX_{ik}$. Also, if there is an overtime premium, then W_{ik} will jump to the higher wage when X_{it} exceeds the overtime threshold. In contrast, if a laborer spends part of her time training new labor, and this time reduces the direct input of her labor into $Q^i(\cdot)$, then payments to labor remain unchanged as dX_{ik} remains unchanged, but output falls because of the substitution of labor to training activities. This fall in output is captured in F_i.

One feature of PL which differentiates it from its predecessors is the possibility of "jumps" arising from the existence of frictions. For example, hiring and firing costs can can lead plants to make large discrete changes when they do change inputs, as in Caplin and Krishna (1986) and Bentolila and Bertola (1990). These types of discrete changes can also lead to jumps in consumption, as in Benhabib and Rustichini (1991). The costs themselves may also take the form of discrete payments made at the time of hiring or firing. There is a large literature in time-series on point (or jump) processes, like generalized Poisson models, and these processes can be applied in our framework.[4]

[4] In the literature on "Stochastic Integration with Jumps" processes dX are typically written as the sum of three

Decomposing PL

Lemma 1 provides the levels and growth-rate decomposition for PL.

Lemma 1

If

$$PL \equiv \sum_i P_i dY_i - \sum_i \sum_k W_{ik} dX_{ik}, \tag{2}$$

then assuming $Q^i(\cdot)$ is once differentiable for all i,

$$PL = \sum_i \sum_k (P_i \frac{\partial Q}{\partial X_{ik}} - W_{ik}) dX_{ik} + \sum_i \sum_j (P_i \frac{\partial Q}{\partial M^i_j} - P_j) dM^i_j - \sum_i P_i dF_i + \sum_i P_i d\omega_i. \tag{3}$$

In growth rates we have

$$PL = \sum_i D_i \sum_k (\varepsilon_{ik} - s_{ik}) dlnX_{ik} + \sum_i D_i \sum_j (\varepsilon_{ij} - s_{ij}) dlnM^i_j - \sum_i D_i dlnF_i + \sum_i D_i dln\omega_i, \tag{4}$$

where the Domar weight is $D_i = \frac{P_i Q_i}{\sum_{i=1}^N P_i Y_i}$, ε_{ik} and ε_{ij} are the elasticities of output with respect to each potential $K * N$ input, and s_{ij} and s_{ik} are the respective revenue shares for each input.

See Appendix for proof. The first two terms in each expression relate to reallocation, with a "gap" term for every primary and intermediate input. The third term relates to changes in F_i and the final term arises from changes in technical efficiency.

In the neoclassical setting, $F_i = 0$ as there are no fixed or sunk costs of adjustment. Optimizing firms set marginal revenue products equal to input prices, so

$$P_i \frac{\partial Q}{\partial X_{ik}} = W_{ik} \, \forall i, k,$$

and similarly $P_i \frac{\partial Q}{\partial M^i_j} = P_j \, \forall i, j$. All that remains as a source of growth are increases in technical efficiency.

We emphasize that - in the neoclassical setting - inputs are being continuously reallocated across plants in response to technical efficiency shocks, so there would be a fall in final demand if inputs were restricted from moving across plants. The main point of (3) is that even though inputs are being reallocated, if marginal revenue products all equal input prices, then further reallocation of inputs cannot lead to an increase in aggregate potential consumption.

---

terms. The first term is deterministic. The second term is stochastic and continuous, but not differentiable, often written as Brownian motion. The final term is the "jump" term, and is often modeled as Poisson.

Reallocation

A simple example of the mechanism at work is given by a two-plant economy with one primary input. Assume common input prices so $W_1 = W_2$. Assume no technical efficiency growth and no costs outside of those measured in the primary input term, so $d\omega_1 = d\omega_2 = dF_1 = dF_2 = 0$. Assume some friction exists such that

$$P_1 \frac{\partial Q}{\partial X_{1k}} > P_2 \frac{\partial Q}{\partial X_{2k}}.$$

Suppose a reduction in the friction leads to a shift of primary input from plant 2 to plant 1 of $dX = dX_1 = -dX_2$. Then final demand increases by

$$(P_1 \frac{\partial Q}{\partial X_{1k}} - P_2 \frac{\partial Q}{\partial X_{2k}})dX,$$

as output that is lost at j is replaced by the more highly valued output from i. More generally, if input prices are identical across plants, so $W_{ik} = W_k \;\; \forall i, k$, then the change in PL arising from the reallocation of primary inputs is given by

$$\sum_i \sum_k (P_i \frac{\partial Q}{\partial X_{ik}} - P_j \frac{\partial Q}{\partial X_{jk}})dX_{ijk} \tag{5}$$

where dX_{ijk} is the amount of input k moving from plant j to plant i and zero otherwise.

Taxes, markups, and adjustment costs all drive a wedge between the the input terms in (3). A tax of τ on a good reduces the marginal revenue of the kth input from $P_i \frac{\partial Q}{\partial X_{ik}}$ to $\frac{1}{1+\tau} P_i \frac{\partial Q}{\partial X_{ik}}$. As a result, optimizing plants produce at a level of output where $P_i \frac{\partial Q}{\partial X_{ik}} > W_{ik}$. PL increases if resources are reallocated to i, as long as they do not come from a plant that already has a larger gap on the kth input.

We use the 2-good world above to consider markups. Markups lead to a situation where

$$\mu_1 = P_1 \frac{\partial Q}{\partial X_{1k}} - W_k > 0$$

and

$$\mu_2 = P_2 \frac{\partial Q}{\partial X_{2k}} - W_k > 0.$$

If $\mu_1 > \mu_2$ then PL increases if input k moves from plant 2 to plant 1.

Adjustment costs for an input can impact the gaps from (3) in several ways.[5] The cost of adjustment leads to ranges of demand/productivity shocks such that the plant does not continuously

[5] A large literature on adjustment costs derives implications of the adjustment costs for the input demand equations directly (see the review in Bond and Reenan (ming)). Caballero and Engel (1993) and Caballero and Engel (1999) infer fixed costs of adjustment for capital by forecasting the optimal level of capital for plants, and then showing that the probability of adjustment is increasing in the difference between this optimal level and the observed level of capital. Cooper and Willis (2001) and Cooper and Willis (2003) challenge this approach, arguing that it is very sensitive to the modeling choice for calculating optimal capital. Bloom, Bond, and Reenan (2007) explore the implications of uncertainty for adjustment.

adjust inputs to satisfy the condition that current marginal revenue from an input equal its current marginal cost. For plants that do adjust, they adjust to levels of the inputs which set expected revenue equal to expected costs. Expected costs now reflect these adjustment costs, so even for plants that adjust they adjust to a level that does not set current marginal revenue product equal to the current input price.

Measuring the fall in aggregate final demand that arises because of the introduction of frictions in the economy has been the focus of much research, including Hopenhayn and Rogerson (1993), Petrin and Sivadasan (2006), Hsieh and Klenow (2007), and Restuccia and Rogerson (2007). In order to determine the cost in allocative efficiency of such a policy, the researcher must determine how inputs would have been distributed but for the policy. Given the "but for" distribution of inputs, the first two terms in the decomposition (3) provide the basis for the calculation of the impact of the frictions on aggregate final demand.

The Domar Weight

The importance of the Domar weight is evident in (4). In the neoclassical case, the Domar weight is the multiplier that aggregates the distribution of plant-level technical-efficiency growth rates to PL. With $F_i = 0\,\forall i$, $P_i \frac{\partial Q}{\partial X_{ik}} = W_{ik}\,\forall i, k$, and $P_i \frac{\partial Q}{\partial M_j^i} = P_j\,\forall i, j$

$$PL = \sum_{i=1}^{N} \frac{P_i Q_i}{\sum_{i=1}^{N} P_i Y_i} dln\omega_i. \tag{6}$$

In levels we can write $\sum_{i=1}^{N} P_i d\omega_i$, where $d\omega_i$ is number of units of "net output at i" and P_i is the market price. If conditions from Bruno (1978) hold so that a value-added production function is a valid representation of the technology, then one can use the value added production function residuals with its numerically equivalent representation

$$\sum_{i=1}^{N} s_{v_i} dln\omega_i^v, \tag{7}$$

where $dln\omega_i^v$ denotes the instantaneous growth rate in the residual from the value-added production function and s_{v_i} denotes the plant's share of aggregate value added.

When we move outside of the neoclassical setting and gaps arise, $\varepsilon_{ik} \neq s_{ik}$ or $\varepsilon_{ij} \neq s_{ij}$. (4) shows that the Domar weight remains the appropriate weight to apply to these gaps in the aggregation to recover PL.

In Domar's words, the weights are defined in order to allow one to:

be free to take the economy apart, to aggregate one industry with another, to integrate final products with their inputs, and to reassemble the economy once more and possibly over different time units without affecting the magnitude of the Residual.

The weight makes results comparable across studies. Subsets of plants in the economy - such as industries or recent entrants/exiters - can be considered separately, and their relationship to the aggregate is directly known.

In any economy with intermediate inputs the Domar weights will sum to the quantity

$$\frac{\sum_{i=1}^{N} P_i Q_i}{\sum_i P_i Y_i}$$

which is strictly greater than one, so these weights are not shares. The reason that innovations in technical efficiency result in more aggregate final demand than just the magnitude of the innovation itself is due to the role of intermediates, as shown in Hulten (1978). When plant i sends part of its output to use as an intermediate input, technical innovations at plant i lead to more consumption of i in final demand *and* more intermediate deliveries. This has a “ripple-effect”, as an increase to j in intermediate deliveries leads to more output of j, some of which may go directly to final demand and some of which may be sent off as intermediates to plant i or plant k, for example. When the accounting traces out the final impact of the technical innovation at i, the growth rate in final demand equals the Domar weight times the magnitude of the technical innovation. As noted above, in levels we are weighting by the price of output times the additional “net output” arising because of the innovation; the price reflects the value of the additional output whether it is consumed directly or passed on as an intermediate.

Entry and Exit.

The definition of PL accounts for entry and exit as long as the number of goods the economy produces is always bounded above by a finite number M and the sum in PL is taken over all goods that at some time might potentially be produced. Previously we described how a good that is actively being producing shows up in PL. Here we consider a good i and an interval of time (t_0, t_1) when i is not being produced. With no output, $Q_i = 0$ implies that $M_i^j = 0 \forall j$, so $dY_i = dQ_i - \sum_j dM_i^j - dF_i$ is zero on the interior of the interval if $dF_i = 0$. Assuming no intermediates or primary inputs are used over the period, dM_j^i and dX_{ik} will be zero for all j and k, and i contributes zero to PL.

Our setup is general enough to allow plants to incur costs while not undertaking production. These costs might include research and development or other start-up costs associated with future production. If these costs are reflected in dF_i, then dY_i will not be zero for i even though i is not producing output. Similarly additional primary and intermediate input use by i will also appear in PL in their usual manner.

Suppose i enters at time t_1. When entry occurs $dQ_i(t_1) > 0$. Some of the output may go to final demand while some may go to intermediate use. This will be reflected in PL in dY_i and and dM_i^j for some or all j. In almost all cases primary and intermediate input use will increase simultaneously, being reflected in dM_j^i and dX_{ik}. These increases might also lead to fixed or sunk costs associated with changing these input levels. For example, if there is a one-time entry cost, then $F_i(t_1)$ would reflect that cost if it occurred at exactly the time of entry.

Similarly, for a good that exits at t_2, $dQ_i(t_2)$ will take the good to zero output, and after exit $dQ_i = 0$. Typically this will take primary and intermediate input to zero. dF_i can reflect shutdown costs such as severance pay. Sell-off value of the assets will show up as a transfer, as $dF_i > 0$ and dF_k will contain a negative term equal to the amount that any k purchased of i's assets.

Our measure of PL is not designed to capture surplus gains or losses that occur because of jumps within the system that arise with the entry and exit of goods. Specifically, PL will not count surplus gains in the case where entry occurs below the price at which demand for the good is zero. Similarly, it will not count surplus losses that occur because goods the exit before the availability of substitutes lowers their demand to zero at given prices. In principle it is easy to adjust the PL measure to account for these changes by defining a new variable $S_i(t)$ for every good i which reflects the current surplus associated with the good. Then dS_i will reflect the change in surplus, and this can be added to PL to produce a new aggregate measure. Measuring dS_i is likely to require more than just the available plant-level data (see Petrin (2002) and Goolsbee and Petrin (2004)).

3. The Bailey-Hulten-Campbell Index and Decomposition, Including Variants

In this section we compare PL with the aggregate productivity growth index proposed by Bailey et al. (1992) and the wide number of variants based upon it, as found in Foster et al. (2001) and Olley and Pakes (1996). In continuous time the original BHC index is given as:

$$BHC \equiv d\sum_i (s_i\, ln\omega_i) = \sum_i s_i\, dln\omega_i + \sum_i ln\omega_i\, ds_i \qquad (8),$$

where s_i is either the gross-output share or the labor share for plant i. The BHC measure decomposes into the two right-hand-side terms. The first term is referred to as the technical efficiency term and the second term is known as the reallocation term.

On the technical efficiency term, the BHC-type indexes use either labor share or gross output share as the weight. There is no reason to believe labor share should equal the Domar weight. The only case in which the Domar weight will equal the gross output share is when there are no intermediate input deliveries in the economy. Otherwise the difference between the two is increasing in the fraction of gross output that goes to intermediate input use.

The BHC reallocation term uses the log-level productivity residual for the plant as the weight applied to the change in share. If we suppose the BHC term is constructed using labor share, in which case it will certainly diverge from PL on the technical efficiency measure, then the difference between PL reallocation and BHC reallocation is driven by how the log-level efficiency term relates to the gaps in (3). In equilibrium plants choose input levels to equate expected marginal revenue with expected cost of the input, *regardless of their productivity level,* providing no reason to believe productivity levels will be correlated with the gaps, let alone equal to them in magnitude. Finally, even when the BHC reallocation term uses the labor share, it accounts for only one input, whereas (3) sums across all inputs.

The divergence from aggregate consumption that the BHC reallocation index exhibits relative to the PL reallocation term is undesirable for two more related reasons. One major disadvantage of using the BHC reallocation term is that it fails to be zero when there is no gain to aggregate final demand from the reallocation of inputs. The BHC reallocation term will generally be non-zero whenever inputs are reallocated, including the case when marginal revenue product equals input price for all plants in the economy. By construction (5) ensures that the PL measure will always equal zero for the reallocation growth in this case.

The second consequence of defining reallocation as in BHC is that it is easy to construct examples where the BHC index is negatively correlated with aggregate potential consumption. One example is an economy where the neoclassical assumptions hold except we have decreasing returns to scale. Each plant has a different efficiency level, but both produce because of the decreasing returns to scale. If we start from the socially optimal outcome where marginal revenue products are equated with the common input price, and we apply a tax to the less efficient plant, then inputs will move to the more efficient plant as the less efficient plant contracts its output to reflect the fall in its marginal revenue product. Aggregate output will fall. BHC will increase and PL will fall. We provide a more detailed example next.

Hotelling Line Model

Our setting has identical goods plus transportation costs, which can be viewed as heterogeneity in tastes for differentiated products. We allow for different efficiency levels for producers. We derive the formula for surplus with and without a tax on the inefficient producer and show how PL and BHC change as the tax is increased.

We use the classic Hotelling setup with consumers distributed across the unit interval uniformly, with x denoting their location on [0,1], and with competition Bertrand-Nash in prices. Plant 0 is located at the left endpoint and Plant 1 at the right endpoint. Plant i's technical efficiency is denoted c_i, the per unit cost of production. To simplify discussion we assume a common demand intercept for both goods $q_0 = q_1 = q^*$ and a common slope for price normalized to -1. We define total surplus as consumer surplus plus producer surplus. t is the transportation cost or heterogeneity in taste. τ denotes the tax on good 0.

Lemma 2

Assume $c_0 > c_1$. Assume a consumer located at x values good 0 at

$$q^* - p_0 - t * x$$

and good 1 at

$$q^* - p_1 - t * (1 - x).$$

Then total surplus W is equal to

$$W(\tau) = q^* - \frac{1}{2}t - c_1 + (c_1 - c_0)x^*(\tau) + tx^*(1 - x^*(\tau)),$$

and

$$\frac{\partial W}{\partial \tau} = (c_1 - c_0)\frac{\partial x^*}{\partial \tau} + t * (1 - 2x^*)\frac{\partial x^*}{\partial \tau}.$$

The tax τ^* that maximizes surplus is

$$\tau^* = 2(1 - \frac{c_1}{c_0}).$$

See Appendix for proof. For any level of τ at which both plants produce the indifferent consumer is given by

$$x^* = \frac{1}{2} - \frac{1+\tau}{6t}c_0 + \frac{1}{6t}c_1.$$

$\frac{\partial x^*}{\partial \tau} < 0$ as the tax induces an output shift from plant 0 to plant 1. For any level of τ at which both firms are producing, a small increase in the tax leads to a savings of $(c_1 - c_0)\frac{\partial x^*}{\partial \tau}$ in costs.

Consumer surplus falls by $(1-2x^*(\tau))\frac{\partial x^*}{\partial \tau}$, as the additional output from plant 1 is valued less than the lost output from plant 0. The optimal tax τ^* trades these margins off,

$$c_0 - c_1 = (1 - 2x^*(\tau^*)).$$

On the interval $[0, \tau^*)$ increases in the tax increase total surplus as $c_0 - c_1 > (1 - 2x^*)$. Both PL and BHC will increase as τ increases here, although only PL will exactly equal the change in total surplus as BHC does not count the cost to consumer surplus. Once $\tau > \tau^*$, total surplus falls as the tax increases because $c_0 - c_1 < (1 - 2x^*)$. PL exactly equals the fall in surplus as the tax increases. BHC continues to increase even after $\tau > \tau^*$ and is thus *negatively* correlated with total surplus over this range.

4. Data and Estimation

We turn to two manufacturing censuses to explore the empirical issues that we raise. One census is from Chile's Instituto Nacional de Estadistica (INE), and the second is from Colombia's Departamento Administrativo Nacional de Estadistica (DANE.) The Chilean data span the period 1987 through 1996 and the Colombian data span the years 1981-1991. We focus on 3-digit industries with more than 200 observations, of which there are 23 in Chile and 26 in Colombia. Here, we provide a brief overview of these data. They have been used in numerous other productivity studies, and we refer the interested reader to those papers for a more detailed data description.[6]

The data are unbalanced panels and cover all manufacturing plants with at least ten employees. Plants are observed annually and they include a measure of output, two types of labor, capital, and intermediate inputs. Because of the way our plant-level data are reported, we treat plants as firms, although there are probably multi-plant firms. Real value added is nominal value added adjusted by the 3-digit industry price index. Labor is the number of man-years hired for production, and plants distinguish between their blue- and white- collar workers. The method for constructing the real value of capital is documented in Liu (1991) for the Chilean data, and a similar approach is adopted for the Colombian data.[7] A data problem for the Chilean census is that approximately 3%

[6] See Liu (1991), Liu (1993), Liu and Tybout (1996), Tybout, de Melo, and Corbo (1991), Pavcnik (2002), Levinsohn (1999), and Levinsohn and Petrin (2003).

[7] It is a weighted average of the peso value of depreciated buildings, machinery, and vehicles, each of which is assumed to have a depreciation rate of 5%, 10%, and 20% respectively. No initial capital stock is reported for some plants, although investment is recorded. When possible, we used a capital series that was reported for a subsequent base year. For a small number of plants, capital stock is not reported in any year. We estimated a projected initial capital stock based on other reported plant observables for these plants. We then used the investment data to fill out the capital stock data.

of the plant-year observations appear to be "missing"; a plant id number is present in year $t-1$, absent in year t, and then present again in year $t+1$. We impute the values for these observations using $t-1$ and $t+1$ information (see the Appendix).

We estimate value-added production function parameters for each of the 3-digit industries and use the parameters to estimate the plant-level TFP residuals. For any industry, the production function coefficients are assumed to be constant over time and across plants, although our findings are robust to loosening this assumption. We employ three different approaches to estimating the coefficients: ordinary least squares, revenue shares, and the proxy method from Levinsohn and Petrin (2003), which includes controls to address the correlation of productivity with input choices. For the revenue shares, for each industry we use the average over plants and time of the shares. Our intent here is *not* to compare estimators, as that has been done (again and again) elsewhere. Rather we wish to investigate whether our empirical results on measuring productivity are robust to these common methods of estimation.

5. Results

A necessary condition for PL and the BHC index to agree is that they yield similar results for continuing plants, which make up on average 95% of plant observations in the industries in our data. For these plants we compare the growth-accounting measure with the BHC index for 49 3-digit manufacturing industries from Chile and Colombia.

We acknowledge that our results here may suffer from many of the measurement problems that typically afflict studies using plant-level data. We do not observe plant-level output price deflators for observed revenue and use industry deflators instead. Measurement of capital levels and utilization rates are problematic, as is our insistence on only two types of labor. Of course, these measurement problems will afflict both the PL and the BHC measure below. It should be clear from the definition of PL that any paper that contributes to our understanding of these measurement issues is relevant for the PL measure.[8]

In an attempt to keep the analysis manageable, we start with a detailed description of results for the largest Chilean manufacturing industry. We then describe how these findings generalize.

Our approach is to compare the indexes using the value-added representation of productivity growth, so we use the value-added residual and apply the value-added share weight, as in (7). We apply the same weight in the BHC index calculation, thus abstracting from the usual difference

[8] See e.g. Berndt and Fuss (1986), Morrison and Diewert (1990), Hulten (1992), Morrison (1986a), Morrison (1986b).

between PL and BHC that is induced by BHC using weights that do not aggregate to PL. We normalize to industry value added, which is easily rescaled to aggregate final demand.[9]

The BHC measurement with discrete data is

$$BHC_T = \sum_i s_{G_{iT}} ln\omega_{iT} - \sum_i s_{G_{i,T-1}} ln\omega_{i,T-1}. \tag{9}$$

Given the common weights, we can write

$$BHC_T = \sum_i \frac{(s_{it} + s_{i,t-1})}{2} ln(\frac{\omega_{it}}{\omega_{i,t-1}}) + \sum_i \frac{(ln\omega_{it} + ln\omega_{i,t-1})}{2} * \Delta s_i, \tag{10}$$

where a Tornquist approximation is used, as advocated (e.g.) in Diewert (1976). The first term is the technical efficiency term and the common weight ensures that BHC and PL agree on aggregate technical efficiency growth. The second term is the BHC reallocation term which we calculate and compare to industry value added.

Table 1 reports the annual estimates of growth rates in productivity for the two measures for ISIC 311, the Food Products industry (the largest in Chile). The production function coefficients are estimated using ordinary least squares, and the productivity calculations use only plants that exist in period $t-1$ and period t (the continuers), which in this industry account for 94.4% of plant-year observations and 96.4% of industry value added over the sample period. Column 1 is the growth in real industry value added for 1988 to 1996, column 2 is the growth-accounting measure of productivity, column 3 is the BHC productivity measure, and column 4 is the difference between these two terms, which is equal to the BHC "reallocation" term described earlier when the correct aggregation weight is used (here value-added share).

The growth-accounting measure averages 3.64% per annum when scaled by industry value-added, with standard deviation of 4.72% across the nine years. On average it accounts for slightly less than one-half of the growth rate in value added, which is consistent with the findings reported in Basu and Fernald (2002).[10] The BHC index averages –2.93% per annum with a standard deviation of 13.48% and diverges widely from the growth rate of value added.

The difference between column 2 and column 3 is the BHC reallocation term (column 4) and it accounts for the erratic behavior of the overall BHC productivity growth index. It has a mean of -6.57%, with a standard deviation of 10.74%. Its volatility across the sample period is consistent

[9] We are working on the results that aggregate all of manufacturing as intermediate inputs play an important role in these industries.

[10] Their approach differs principally in their use of U.S. data that has been aggregated to the industry level.

with the general findings in the literature that BHC reallocation can be large and volatile. The general magnitudes and movements of BHC reallocation also appear unrelated to aggregate value added.

For ISIC 311, table 2 compares estimates of productivity growth across different estimators for production function parameters. The top half of the table is the technical efficiency measure and the bottom half is the BHC index. For the top half, column 2 is the same as column 2 from table 1, which uses ordinary least squares to obtain production function estimates. Column 3 uses the proxy approach from Levinsohn and Petrin (2003), and column 4 uses revenue shares. While the production function estimates (not reported here) do differ somewhat across the three approaches, the productivity growth numbers using the technical efficiency index are reasonably similar across the three estimators.

For the BHC index, the signs tend to be common across the three sets of production function estimates, but the magnitudes are quite different, with the LP and OLS estimates systematically the largest in absolute value terms. The main reason for the volatility is reflected in the "reallocation" terms, which are systematically more volatile for LP and OLS relative to revenue shares.

The main result is that the micro patterns observed in the largest industries in Chile are indicative of the findings for the entire 49 3-digit industries from both countries.[11]

6. Conclusions

In this paper we have shown how to extend the traditional definition of aggregate productivity growth to plant-level data. Specifically, we show how to aggregate plant-level data to PL, and how to use plant-level data to decompose PL into several terms, including a term that aggregates changes in plant-level technical efficiency, and several more terms related to the reallocation of inputs across plants. The extension requires us to confront the "non-neoclassical" features that impact plant-level data, including related factors like plant-level heterogeneity, the entry and exit of goods, fixed and sunk costs, markups, returns to scale, adjustment costs like hiring, firing and search costs, gestation lags, and sub-optimal behavior of plants.

Our measure of PL has several attractive features. It is in the spirit of the history of productivity growth measures that use aggregate data to track final demand and input costs. There is an enormous literature on estimating technical efficiency and there is a growing literature on estimating the difference between mariginal revenue products and input prices at the plant-level (see e.g. Petrin

[11] Results available on request.

and Sivadasan (2006)). While the assumptions necessary for our indicator of potential consumption to equal welfare are strong, many theoretical models of growth write down welfare functions that are special cases of PL. The definition also provides practitioners with a measurement useful for cost-benefit/policy analysis that is readily comparable across time, industries, countries, and empirical studies.

We compare PL to several variants of the widely used indexes proposed in Bailey et al. (1992), including those in Olley and Pakes (1996), and Foster et al. (2001). While these indexes have decompositions into technical efficiency and reallocation terms that are similar in spirit to those from PL, economic theory indicates that the BHC measure will depart from the PL measure on both dimensions. Perhaps the biggest difference is on the definition of reallocation. PL weights input movements using differences in the gaps between marginal revenue products and input prices, as in (5). BHC weights input movements using differences in technical efficiency across plants, as in (10). In equilibrium plants choose input levels to equate expected marginal revenue with expected cost of the input, regardless of their level of technical efficiency. Thus the BHC measure uses no information the differences between marginal revenue products and input prices in its assessment of growth arising from reallocation.

Our theoretical findings are consistent with our empirical findings for manufacturing industries in Chile and Colombia, where the BHC index and its reallocation component behave erratically relative to the growth in technical efficiency and value added. Papers relating theory to empirics have also reported finding that the BHC index either misses or is even negatively correlated with growth in aggregate consumption. By its definition PL cannot have that problem. Empirical measurement is another question and the topic of future research.

References

Aghion, P., and Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, *60*(2), 323–351.

Aghion, P., and Howitt, P. (1994). Growth and unemployment. *Review of Economic Studies*, *61*(3), 477–494.

Bailey, M., Hulten, C., and Campbell, D. (1992). Productivity dynamics in manufacturing plants. In *Brookings Papers on Economic Activity: Microeconomics*, Vol. 4, pp. 187–267. Brookings Institute.

Bartelsman, E., Haltiwanger, J., and Scarpetta, S. (2006). Cross country differences in productivity: The role of allocative efficiency. Working Paper.

Basu, S., and Fernald, J. (2002). Aggregate productivity and aggregate technology. *European Economic Review*, *46*, 963–991.

Benhabib, J., and Rustichini, A. (1991). Vintage capital, investment, and growth. *Journal of Economic Theory*, 323–339.

Bentolila, S., and Bertola, G. (1990). Firing costs and labour demand: How bad is eurosclerosis?. *Review of Economic Studies*, *57*(3), 381–204.

Berndt, E., and Fuss, M. (1986). Productivity measurement with adjustments for variations in capacity utilization and other forms of temporary equilibrium. *Journal of Econometrics*, *33*, 7–29.

Berry, S., and Tamer, E. (2006). Identification in models of oligopoly entry. Working Paper.

Bloom, N., Bond, S., and Reenan, J. V. (2007). Uncertainty and investment dynamics. *Review of Economic Studies*, *74*, 391–415.

Bond, S., and Reenan, J. V.). *Handbook of Econometrics*, chap. Microeconometric Models of Investment and Employment. North-Holland.

Bresnahan, T., and Reiss, P. (1991). Entry and competition in concentrated markets. *Journal of Political Economy*, *99*(5), 997–1009.

Bruno, M. (1978). *An Analysis of the Concept of Real Value-Added, in Production Economics: A Dual Approach to Theory and Applications*, chap. III.1. North-Holland.

Caballero, R., and Engel, E. (1993). Microeconomic adjustment hazards and aggregate dynamics. *Quarterly Journal of Economics*, *108*(2), 359–383.

Caballero, R., and Engel, E. (1999). Explaining investment dynamics in u.s. manufacturing: A generalized (s,s) approach.. *Econometrica*, *67*(4), 783–826.

Caballero, R., and Hammour, M. (1994). The cleansing effect of recessions. *American Economic Review*, *84*(5), 1350–1368.

Caballero, R., and Hammour, M. (1996). On the timing and efficiency of creative destruction. *The Quarterly Journal of Economics*, *111*(3), 805–852.

Campbell, J. (1998). Entry, exit, embodied technology, and business cycles. *Review of Economic Dynamics*, *1*(2), 371–408.

Caplin, A., and Krishna, K. (1986). A simple dynamic model of employment. Mimeo, Harvard University, Cambridge, Mass.

Cooper, R., and Willis, J. (2001). The economics of labor adjustment: Mind the gap. NBER Working Paper No. 8527.

Cooper, R., and Willis, J. (2003). The cost of labor adjustment: Inferences from the gap. NBER Working Paper No. 10006.

Diewert, E. (1976). Exact and superlative index numbers. *Journal of Econometrics*.

Ericson, R., and Pakes, A. (1995). Markov-perfect industry dynamics: A framework for empirical work. *Review of Economic Studies*, *62*(1), 53–82.

Foster, L., Haltiwanger, J., and Krizan, C. (2001). *New Developments in Productivity Analysis*, chap. Aggregate Productivity Growth: Lessons from Microeconomic Evidence, pp. 303–372. University of Chicago Press.

Goolsbee, A., and Petrin, A. (2004). The consumer gains from direct broadcast satellites and the competition with cable TV. *Econometrica*, *72*(2), 351–382.

Hall, R. (1990). Invariance properties of solow's productivity residual. In Diamond, P. (Ed.), *Growth/Productivity/Unemployment: Essays to Celebrate Bob Solow's Birthday*. MIT Press.

Hopenhayn, H., and Rogerson, R. (1993). Job turnover and policy evaluation: A general equilibrium analysis. *Journal of Political Economy*, *10*(5), 915–938.

Hsieh, C.-T., and Klenow, P. J. (2007). Misallocation and manufacturing tfp in china and india. NBER Working Paper 13290.

Hulten, C. (1978). Growth accounting with intermediate inputs. *The Review of Economic Studies*, *45*(3), 511–518.

Hulten, C. (1992). Growth accounting when technical change is embodied in capital. *American Economic Review*, *82*(4), 964–980.

Lentz, R., and Mortensen, D. (2007). An empirical model of growth through product innovation. Working Paper.

Levinsohn, J. (1999). Employment responses to international liberalization in Chile. *Journal of International Economics*, *47*, 321–244.

Levinsohn, J., and Petrin, A. (1999). When industries become more productive, do firms? investigating productivity dynamics. NBER Working Paper 6893.

Levinsohn, J., and Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *Review of Economic Studies*, *70*(2), 341–372.

Liu, L. (1991). *Entry-Exit and Productivity Changes: An Empirical Analysis of Efficiency Frontiers*. Ph.D. thesis, University of Michigan.

Liu, L. (1993). Entry, exit, and learning in the Chilean manufacturing sector. *Journal of Development Economics*, *42*, 217–242.

Liu, L., and Tybout, J. (1996). Productivity growth in Colombia and Chile: Panel-based evidence on the role of entry, exit and learning. In Roberts, M., and Tybout, J. (Eds.), *Producer Heterogeneity and Performance in the Semi-Industrialized Countries*, chap. 4. World Bank.

Melitz, M. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*.

Morrison, C. (1986a). *Capacity Utilization and Productivity Measurement: An Application to the U.S. Automobile Industry*. Kluwer Nijhoff, Boston.

Morrison, C. (1986b). Productivity measurement with nonstatic expectations and varying capacity utilization: An integrated approach. *Journal of Econometrics*, *33 1/2*.

Morrison, C., and Diewert, E. (1990). New techniques in the measurement of multifactor productivity. *The Journal of Productivity Analysis*.

Mortensen, D., and Pissarides, C. (1994). Job creation and job destruction in the theory of unemployment. *Review of Economic Studies*.

Olley, S., and Pakes, A. (1996). The dynamics of productivity in the telecommunications equipment industry. *Econometrica*, *64*(6), 1263–1298.

Pavcnik, N. (2002). Trade liberalization, exit, and productivity improvements: Evidence from Chilean plants. *Review of Economic Studies*, *69*, 245–276.

Petrin, A. (2002). Quantifying the benefits of new products; the case of the minivan. *Journal of Political Economy*, *110*, 705–729.

Petrin, A., and Sivadasan, J. (2006). Job security does affect economic efficiency: Theory, a new statistic, and evidence from chile. NBER Working Paper 12757.

Restuccia, D., and Rogerson, R. (2007). Policy distortions and aggregate productivity with heterogeneous plants. Working Paper 283, Department of Economics, University of Toronto.

Sweeting, A. (2006). Estimating radio station format switching costs. Northwestern University Working Paper.

Tybout, J., de Melo, J., and Corbo, V. (1991). The effects of trade reforms on scale and technical efficiency: New evidence from Chile. *Journal of International Economics*, *31*, 231–250.

Appendix

Proof of Lemma 1

Multiply $dY_i = dQ_i - \sum_j dM_i^j - dF_i$ by P_i and aggregate over all i to get an expression for the change aggregate value added:

$$\sum_i P_i dY_i = \sum_i P_i dQ_i - \sum_i P_i(\sum_j dM_i^j) - \sum_i P_i dF_i. \tag{11}$$

Totally differentiate $Q_i = Q^i(X^i, M^i, \omega_i)$ and multiply by P_i to get

$$P_i dQ_i = \sum_k P_i \frac{\partial Q}{\partial X_{ik}} dX_{ik} + (\sum_j P_i \frac{\partial Q}{\partial M_j^i} dM_j^i) + P_i d\omega_i.$$

Substituting into (11), deducting $\sum_i \sum_k W_{ik} dX_{ik}$, and rearranging yields the decomposition of PL in levels. Translating to growth rates follows immediately. #

Proof of Lemma 2

Given prices the indifferent consumer is

$$x^* = \frac{1}{2t}(p_1 - p_0 + t).$$

Plants 0 and 1 choose prices to maximize $(p_0 - c_0)x^*$ and $(p_1 - c_1)(1 - x^*)$ respectively. With $\tau = 0$ equilibrium prices are

$$p_0 = t + \frac{2}{3}c_0 + \frac{1}{3}c_1,$$

and symmetrically for plant 1. In terms of costs, the indifferent consumer becomes

$$x^* = \frac{1}{2} - \frac{1}{6t}c_0 + \frac{1}{6t}c_1.$$

If we apply a tax τ to good zero then equilibrium prices are given as

$$p_0 = t + \frac{2(1+\tau)}{3}c_0 + \frac{1}{3}c_1,$$

$$p_1 = t + \frac{1+\tau}{3}c_0 + \frac{2}{3}c_1,$$

and

$$x^* = \frac{1}{2} - \frac{1+\tau}{6t}c_0 + \frac{1}{6t}c_1.$$

With tax revenues added back to consumption total surplus is given as

$$W = \int_0^{x^*} (q^* - p_0 - tx)dx + \int_{x^*}^1 (q^* - p_1 - t(1-x)dx + (p_0 - c_0)x^* + (p_1 - c_1)(1 - x^*),$$

which gives

$$W = q^* - \frac{1}{2}t - c_1 + (c_1 - c_0)x^* + tx^*(1 - x^*).$$

$\frac{\partial W}{\partial \tau}$ and the optimal tax follow immediately. #

Imputing Missing Values

Approximately 3% of the plant-year observations in Chile are "missing" according to the following definition: a plant id number is present in year $t-1$, absent in year t, and then present again in year $t+1$. We impute the values for these observations using $t-1$ and $t+1$ information and the structure of the estimated production function. We use the simple average of the $t-1$ and $t+1$ (log) productivity estimates for the period t productivity estimate. Similarly, we use the simple average of the $t-1$ and $t+1$ (log) input index estimates, where the weights in the index are the estimated production function parameters. All of our findings are robust to dropping these observations.

TABLE 1

Comparison of the Growth-Accounting Index with the BHC Productivity Index

Ordinary Least Squares Estimates, ISIC 311, Chile

	Rate of Growth in:			
Year	Value Added	Growth-Accting Index $\sum_i \frac{(s_{it}+s_{i,t-1})}{2} ln(\frac{\omega_{it}}{\omega_{i,t-1}})$	BHC Index $\sum_i s_{it} ln\omega_{it} - \sum s_{i,t-1} ln\omega_{i,t-1}$	Difference (BHC "Reallocation" Term) $\sum_i \frac{(ln\omega_{it}+ln\omega_{i,t-1})}{2} * \Delta s_i$
1988	11.75	-3.12	-14.96	-11.84
1989	7.36	3.64	-7.45	-11.10
1990	4.59	-1.10	-10.52	-9.43
1991	13.82	7.36	-13.28	-20.63
1992	14.67	6.09	-8.11	-14.20
1993	8.98	5.09	-0.19	-5.28
1994	8.20	2.95	7.09	4.13
1995	7.06	-0.74	-7.24	-6.50
1996	-1.30	12.56	28.25	15.69
Average	8.35	3.64	-2.93	-6.57
Std. Dev.	4.89	4.72	13.48	10.74

The last column is the discrepancy between the BHC index and the growth-accounting index, which is equal to a reallocation-like term given by $\sum_i \overline{ln\omega_i} * \Delta s_i$. The comparison is done on firms that exist in period t and $t-1$, which account for 94.4% of the plant-year observations and 96.4% of industry value added. See text for details.

TABLE 2

Comparison of Productivity Indexes Across

OLS, Levinsohn-Petrin, and Revenue Share Productivity Estimates

ISIC 311, Chile

Year	Value Added	OLS	Levinsohn-Petrin	Revenue Shares
Growth-Accting Index				
1988	11.75	-3.12	-0.04	0.77
1989	7.36	3.64	4.39	4.86
1990	4.59	-1.10	-1.26	-1.91
1991	13.82	7.36	7.68	8.98
1992	14.67	6.09	6.82	9.69
1993	8.98	5.09	5.87	4.41
1994	8.20	2.95	4.45	2.84
1995	7.06	0.74	1.41	-5.22
1996	-1.30	12.56	11.07	6.80
BHC Index				
1988	11.75	-14.96	-19.16	-5.04
1989	7.36	-7.45	-11.94	-4.40
1990	4.59	-10.52	-20.43	-2.21
1991	13.82	-13.28	-24.42	-4.09
1992	14.67	-8.11	-15.54	-0.01
1993	8.98	-0.19	5.16	0.09
1994	8.20	7.09	4.81	4.33
1995	7.06	-7.24	-9.09	-10.40
1996	-1.30	28.25	39.66	1.07

Growth rates in productivity compared across methods used to estimate production function parameters. Comparison is done on firms that exist in period t and $t-1$.