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SOURCES OF PRODUCTIVITY GROWTH: TECHNOLOGY, TERMS OF TRADE, AND PREFERENCE SHIFTS

By Thijs ten Raa and Pierre Mohnen

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Sources of Productivity Growth: Technology, Terms of Trade, and Preference Shifts

Thijs ten Raa
Tilburg University

Pierre Mohnen[1]
Université du Québec à Montréal and CIRANO

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Abstract.
The standard measure of productivity growth is the Solow residual. Its evaluation requires data on factor input shares or prices. Since these prices are presumed to match factor productivities, the standard procedure amounts to accepting at face value what is supposed to be measured. In this paper we determine total factor productivity growth without recourse to data on factor input prices. Factor productivities are defined as Lagrange multipliers to the program that maximizes the level of domestic final demand. The consequent measure of total factor productivity is shown to encompass not only the Solow residual, but also terms-of-trade and preference-shift effects. Using input-output tables from 1962 to 1991 we show that the source of Canadian productivity growth has shifted from technical change to terms-of-trade effects.

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1 Introduction

The measurement of total factor productivity (TFP)-growth constitutes a conceptual puzzle. It involves the use of wage and rental rates to construct an input aggregate. The growth rate of the latter is compared with the growth rate of output. When output grows faster than input, there is productivity growth, room for increases in factor rewards. Indeed, estimates of productivity growth are used to define the 'room' in collective wage bargaining. However, since the underlying TFP measure hinges on wage and rental rates, there is some circularity in the reasoning.

The puzzle is resolved for perfectly competitive economies. In such economies factor inputs are rewarded according to their marginal productivities. TFP can be conceived as the sum of these marginal productivities taken over all factor inputs. The consequent growth rate agrees with the so called Solow residual measure of TFP-growth. Jorgenson and Griliches (1967) and Solow (1957) have shown the equivalence with the shift of the production possibility frontier. The trouble is, however, that observed economies are not perfectly competitive. They are not even on their production possibility frontiers. If we nonetheless stick to the conventional measures of TFP-growth, employing observed value shares for labor and capital, it is not clear what we get. The residual no longer isolates technical change effects, but also captures variations of the economy about the competitive benchmark, such as changes in market power, returns to scale or the business cycle. The approach of the literature is to correct the Solow residual for those effects, using information on the degrees that the economy departs from the competitive benchmark (Lerner index, returns-to-scale index or utilization rates) and modifying the formula for the residual (Hall, 1990).

Rather than trying to get a handle on the various departures from perfect competition or refining Solow residual expressions by means of inference, this paper attempts to measure factor productivities directly on the basis of the fundamentals of the economy, without recourse to market derivatives, such as factor shares, in the use of weights. The fundamentals are the usual ones: endowments, technology, and preferences. Endowments are represented by a labor force and stocks of capital. Technology is given by the combined inputs and outputs of the sectors of the economy. Preferences are reflected by the pattern of domestic final demand. All the information can be extracted from input and output tables in real terms, that is constant prices. The productivities are determined as follows. We maximize the level of domestic consumption subject to material balances and endowment constraints. Now, as is known from the theory of mathematical programming, the Lagrange multipliers associated with the endowment constraints measure the marginal productivities of labor and capital: the consumption increments per units of additional labor or capital. In economics, these Lagrange multipliers are shadow prices that would reign under idealized conditions of perfect competition. We declare these shadow prices to be the factor productivities.

The main theoretical contributions of our paper are two. First, we demonstrate that the Lagrange multipliers foundation of factor productivities reconciles the frontier approach with the growth accounting literature. The reconciliation is mutually beneficial. As mentioned, the growth accounting literature suffers from some circularity in the reasoning as it employs wage and rental rates. The frontier approach has the potential of determining these values. Conversely, the frontier approach suffers from mechanical output measures and lack of interindustry analysis. We insert an economic criterion in its mathematical program and thus enrich the frontier approach with all the useful ingredients of mainstream TFP-analysis. The second theoretical contribution of our paper is that it discloses the terms-of-trade effect in productivity analysis. It is well known that an improvement in the terms of trade is equivalent to technical progress. In this paper we will demonstrate that TFP-growth based on Lagrange multiplier increases can be decomposed into technical change, preference shift, and terms-of-trade effects. Most of the literature implicitly assumes an aggregated output and, therefore, is unable to detect preference shifts or terms-of-trade effects, identifying TFP-growth with the so-called Solow residual measure of technical change. Diewert and Morisson (1986) capture terms-of-trade effects, but pay a high price in terms of modeling. Commodities must be divided a priori between exports and imports. This is not a tenable assumption over a long period of analysis. Moreover, they assume a jointness in outputs that precludes specialization and even violates global convexity in production, an assumption needed for their analysis. We shall overcome this obstacle, by letting trade be free, including its direction.

The last contribution of our paper is of an applied nature. While the functional forms of the productivity formulas are shown to be perfectly consistent with the literature, the values, particularly of the shares, are now endogenous and hence different. In other words, our approach amounts to a revision of TFP-estimates and decompositions.

The paper is organized as follows. Factor productivities and TFP are defined by means of a linear program in the next section. In section 3 we present the data of the Canadian economy from 1962 to 1991. In section 4 we present our results. The last section concludes.

2 Productivities

We push the economy to its frontier by maximization of the level of domestic final demand, which excludes trade by definition. Exports and imports are endogenous, controled by the balance of payments. We make no distinction between competitive and non-competitive imports. (The latter are indicated by zeros in the make table.)

Domestic final demand comprises consumption and investment. Investment is merely a means to advance consumption, albeit in the future. We include it in the objective function to account for future consumption. In fact, Weitzman (1976) shows that for competitive economies domestic final demand measures the present discounted value of future consumption.

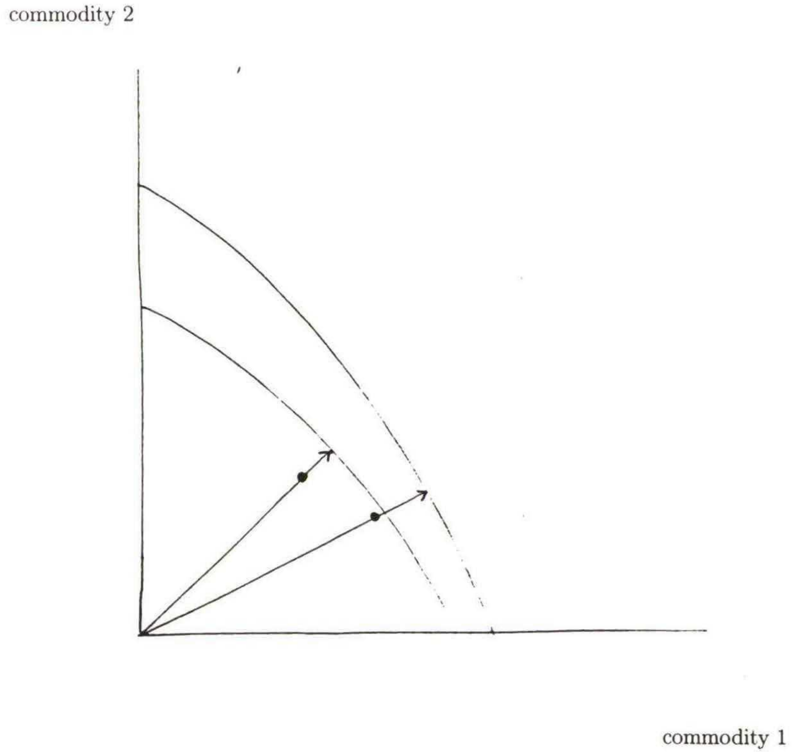

Figure 1.

Productivity growth will be defined as the measure of the shift of the frontier. Instead of comparing observations of the economy in subsequent periods (represented by the dots in Figure 1), we will compare the projections on the respective frontiers (the arrows).

We normalize the level of domestic final demand using base year prices, $e^\top$ for commodities, r^0 for non-business capital stock and w^0 for non-business labor. The primal program reads

$$
\begin{array}{rcl}
\multicolumn{3}{l}{\max_{s,c,g}(e^\top f + r^0 k + w^0 l)c \text{ subject to}} \\
(V^\top - U)s & \geq & fc + Jg =: F \\
Ks + kc & \leq & M \\
Ls + lc & \leq & N \\
-\pi g & \leq & -\pi g^t =: D \\
s & \geq & 0.
\end{array}
\tag{1}
$$

Here the variables (s, c and g) and parameters (all other) are the following [with dimensions in brackets].

s	activity vector [# of sectors]
c	level of domestic final demand [scalar]
g	vector of net exports [# of tradeable commodities]
e	unit vector of all components one
$\top$	transposition symbol
f	domestic final demand [# of commodities]
r^0	base-year rental rate for non-business capital [# of capital types]
w^0	base year price for non-business labor [scalar]
k	non-business capital stock [# of capital types]
l	non-business labor employment [scalar]
V	make table [# of sectors by # of commodities]
U	use table [# of commodities by # of sectors]
J	0-1 matrix placing tradeables [# of commodities by # of tradeables]
F	final demand [# of commodities]
K	capital stock matrix [# of capital types by # of sectors]
L	labor employment row vector [# of sectors]
M	capital endowment $Ke + k$ [# of capital types]
N	labor force [scalar]
π	U.S. relative price row vector [# of tradeables]
g^t	vector of net exports observed at time t [# of tradeables]
D	observed trade deficit [scalar].

Productivities are not measured using market prices, but are determined by the dual program, which, as is well known, solves for the Lagrange multipliers of the primal program. These measure the marginal products of the objective value with respect to the constraining entities, unlike observed factor rewards with all their distortions. The dual program reads

$$\begin{array}{rcl} \min_{p,r,w,\varepsilon \geq 0} \; rM + wN + \varepsilon D \text{ subject to} & & \\ p(V^\top - U) & \leq & rK + wL \\ pf + rk + wl & = & e^\top f + r^0 k + w^0 l \\ pJ & = & \varepsilon \pi . \end{array} \tag{2}$$

The variables in the dual program are shadow prices: p of commodities, r of capital (# of capital types), w of labor and ε of foreign debt (the exchange rate). Since the commodity constraint in the primal program has a zero bound, p does not show up in the objective function of the dual program. p is normalized by the second dual constraint, essentially about unity.[2]

We now introduce the concept of productivity growth. Since labor productivity is the Lagrange multiplier or shadow price associated with the labor constraint, w, labor productivity growth is the growth of w, $\dot{w} = dw/dt$. Similarly, r is the vector of marginal productivities for each type of capital stock and ε the marginal productivity of the trade deficit. Total factor productivity (TFP)-growth is obtained by summing all factor productivity growth figures over endowments, $\dot{r}M + \dot{w}N + \dot{\varepsilon}D$, and normalizing by the level of productivity, $rM + wN + \varepsilon D$. Formally,

Definition.

$$\text{TFP-growth} = (\dot{r}M + \dot{w}N + \dot{\varepsilon}D)/(rM + wN + \varepsilon D). \tag{3}$$

Remark. Replacement of (f, k, l) by $(\lambda f, \lambda k, \lambda l)$ in the primal program with $\lambda > 0$ yields solution $(s, c/\lambda, g)$. The value of the objective function is not affected. By the main theorem of linear programming, $rM + wN + \varepsilon D$ is not either. In fact, the productivities are unaffected, as is, by extension, TFP-growth. The replacement does affect the commodity prices, as to preserve the identity between the national product and the national income, which we present next.

The above straightforward definition of TFP-growth is now related to the commonly used Solow residual. By the main theorem of linear programming, substituting the last constraint of (2), we obtain the macro-economic identity of national product and income (apart from the net exports on either side):

$$pfc + rkc + wlc = rM + wN + \varepsilon D. \tag{4}$$

By total differentiation of (4):

$$\text{TFP-growth} = [(pfc + rkc + wlc)^{\cdot} - r\dot{M} - w\dot{N} - \varepsilon\dot{D}]/(pfc + rkc + wlc) \tag{5}$$

[2] p is not a device to convert nominal values to real values, but a price vector that sustains the optimal allocation of resources in the linear program.

To establish the link with the Solow residual, focus on the numerator,

$$(pF - pJg + rkc + wlc)^{\cdot} - r(Ks + rkc)^{\cdot} - w(Ls + lc)^{\cdot} + \varepsilon(\pi g)^{\cdot}. \tag{6}$$

Differentiating products, rearranging terms, and using the dual constraint and the definition of F presented in the primal program, we obtain

$$\begin{aligned}
& p\dot{F} - r(Ks)^{\cdot} - w(Ls)^{\cdot} \\
& - pJ\dot{g} + \varepsilon(\pi g)^{\cdot} \\
& + \dot{p}(F - Jg) + (rkc)^{\cdot} - r(kc)^{\cdot} + (wlc)^{\cdot} - w(lc)^{\cdot} \\
& = \\
& p\dot{F} - r(Ks)^{\cdot} - w(Ls)^{\cdot} \\
& + \varepsilon\dot{\pi}g \\
& + \dot{p}fc + \dot{r}kc + \dot{w}lc.
\end{aligned} \tag{7}$$

We now have a surprising three-way decomposition of total factor productivity growth.[3] Technical change is represented by only one term, the first one, that is the *Solow residual* (*SR*). In remark 4 below it will be shown that it can be expressed as a weighted sum of sectoral Solow residuals, where the weights change over time as final demand composition effects move the relative importance of sectors (Wolff, 1985). The second term, $\varepsilon\dot{\pi}g$, represents the *terms-of-trade effect.* Since proportional changes in π are offset by a change in ε, only relative international price changes matter. The last term is the *preference shift* effect. To reveal it more closely, recall that $pf + rk + wl$ may be held constant by the remark, so that the preference shift effect may be rewritten as $-(p\dot{f} + r\dot{k} + w\dot{l})c$. If the pattern of domestic final demand, (f, k, l), shifts towards commodities with low opportunity costs, it becomes easier to satisfy the needs and, therefore, TFP is boosted. This preference shift effect comes on top of the just mentioned Wolff (1985) demand effect. The terms-of-trade and preference shifts effects disappear when there is only one commodity and no non-business income. Under these circumstances, π is unity and p also by the second dual constraint, hence their derivatives vanish. In other words, in a macro-economic setting TFP-growth reduces to the Solow residual. It should be mentioned, however, that a tiny difference remains in the denominators. We divide by $pfc+rkc+wlc = pF-pJg+rkc+wlc = pF-\varepsilon\pi g+rkc+wlc = pF+\varepsilon D+rkc+wlc$. In other words, we account for the deficit and non-business incomes.

Examples. In three examples we will highlight the technical change, terms-of-trade, and preference-shift components of TFP-growth. The first two examples feature no trade, but ascribe all TFP-growth to either the Solow residual or the taste effect. The third example illustrates the terms of trade effect. The examples differ by end situation. The base situation is always an economy with labor inputs $L = \begin{pmatrix} \frac{4}{3} & \frac{2}{3} \end{pmatrix}$ and commodity outputs $V = I$. There is no trade, capital, intermediate inputs, or unemployed labor.

[3]Strictly speaking, there should be a fourth term with the slack changes, $-r\dot{\sigma}_M - w\dot{\sigma}_N - \varepsilon\dot{\sigma}_D$, because in deriving (6) all constraints were assumed to be binding.

In the *first* example, labor employment remains the same, but output shifts from commodity 2 to commodity 1, so that V turns $\begin{pmatrix} 1+\delta & 0 \\ 0 & 1-\delta \end{pmatrix}$. The primal program reads

$$\begin{aligned} &\max\ (1+\delta+1-\delta)c \text{ subject to} \\ &\begin{pmatrix} (1+\delta)s_1 \\ (1-\delta)s_2 \end{pmatrix} \geq \begin{pmatrix} (1+\delta)c \\ (1-\delta)c \end{pmatrix} \\ &\tfrac{4}{3}s_1 + \tfrac{2}{3}s_2 \leq 2 \\ &s \geq 0. \end{aligned}$$

The solution is $s_1 = s_2 = c = 1$ with value 2 for the objective function, both in the base situation ($\delta = 0$) and the end situation. By the macro-economic identity w was and is 1. Hence TFP-growth as defined in (3) is zero. There is technical change, however, for output has shifted towards the resource intensive commodity, stepping outside the initial production possibility frontier. The Solow residual is $p\dot{F} = (\frac{4}{3}\ \frac{2}{3}) \begin{pmatrix} +\delta \\ -\delta \end{pmatrix} = \frac{2}{3}\delta$. This is basically the demand composition effect stressed by Wolff (1985). The new demand is unfavorable. The preference shift effect is $\dot{p}fc$. Since s is positive (by the material balance), the first dual constraint is binding (by complimentary slackness), so that the price vector turns $\left(\frac{4/3}{1+\delta}\ \frac{2/3}{1-\delta}\right)$ and, therefore, has derivative $(-\frac{4}{3}\delta\ \frac{2}{3}\delta)$ (for δ small), so that the preference shift effect is $(-\frac{4}{3}\delta\ \frac{2}{3}\delta)\begin{pmatrix} 1 \\ 1 \end{pmatrix}$ (for δ small) or $-\frac{2}{3}\delta$.

The *second* example is similar, but now V turns $\begin{pmatrix} 1-\delta & 0 \\ 0 & 1+2\delta \end{pmatrix}$. The solution to the primal program becomes $(1-\delta+1+2\delta)*1 = 2+\delta$ and the wage rate becomes $1+\frac{\delta}{2}$ to satisfy (4). The gain, $\frac{\delta}{2}$, has to be multiplied by the number of workers, 2, yielding a TFP-growth of δ. It can be ascribed entirely to the preference-shift effect, for the economy shifts along its frontier, foregoing δ of the doubly labor intensive commodity, nr. 1, for 2δ of commodity nr. 2. Hence the Solow residual is zero.

In the *third* example, world prices $(1\ \ 1)$ turn $(1+\delta\ \ 1-\delta)$, while L and V remain the same. The linear program expands the domestic consumption vector, $\begin{pmatrix} 1 \\ 1 \end{pmatrix}$, by letting the economy specialize in the resource extensive commodity, nr. 2. Output is the same before and after the international price change, but the terms of trade detiorate, reducing the level of consumption and, therefore, the real wage rate and TFP.

Remarks.
1. The TFP measure used in Mohnen, ten Raa and Bourque (1997) is confined to the Solow residual without the terms-of-trade and preference-shift effects. It was derived from total differentiation of the complementary slackness conditions of the first constraint of (2). There is also a slight normalization difference. In this paper, we nor-

malize with respect to $rM + wN + \varepsilon D = pfc + rkc + wlc$, whereas Mohnen, ten Raa and Bourque (1997) normalize with respect to $pF = pfc + pJg$.

2. Implicit in our model is the assumption of Leontief preferences over domestic final demand. Retail and banking services are components of the domestic final demand vector. In a way, one might argue that households favor reductions of these components. The smaller the margins, the more efficient the economy. This effect is captured by the preference shift effect component of TFP-growth. Factor productivity gains within these service sectors are captured by the Solow residual

3. In discrete time, the expressions involving differentials are approximated using the identity $x_t y_t - x_{t-1} y_{t-1} = \widehat{x_t}\overline{x_t}\overline{y_t} + \widehat{y_t}\overline{x_t}\overline{y_t}$, where $\widehat{x_t} = (x_t - x_{t-1})/\overline{x_t}$ and $\overline{x_t} = (x_t + x_{t-1})/2$, and similarly for $\widehat{y_t}$ and $\overline{y_t}$.

4. By Domar's aggregation we can decompose the aggregate Solow residual into sectoral and group-sectoral Solow residuals. Let j index the sectors, i the commodities, and k the sector groups. Denote a relative growth rate by $\widehat{L}_j = \dot{L}_j/L_j$. Define the Solow residual of group-sector k as:[4]

$$SR_k = \Sigma_{j \in k}(\Sigma_i p_i v_{ji} s_j \widehat{v}_{ji} - \Sigma_i p_i u_{ij} s_j \widehat{u}_{ij} - wL_j s_j \widehat{L}_j - \Sigma_i r_i K_{ij} s_j \widehat{K}_j)/\Sigma_{j \in k}\Sigma_i p_i v_{ji} s_j$$

Notice that if $k = j$, we get the Solow residual for sector j. It can be shown that our aggregate Solow residual (SR) expression can be written as:

$$SR = \frac{\sum_k \sum_{j \in k} \sum_i p_i v_{ji} s_j}{\sum_i p_i F_i} SR_k. \tag{8}$$

3 Data

We use the input-output tables of the Canadian economy from 1962 to 1991 at the medium level of disaggregation, which has 50 industries and 94 commodities.

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[4]The numerator of the Solow residual of sector j is

$$\Sigma_i p_i [(v_{ji} - u_{ij})s_k]^{\cdot} - \Sigma_i r_i (K_{ij} s_j + \sigma_{ij})^{\cdot} - w(L_j s_j)^{\cdot}$$

The product rule of differentiation yields the term in SR_k, plus, strictly speaking,

$$\Sigma_{j \in k}[\Sigma_i p_i (v_{ji} - u_{ij}) - \Sigma_i r_i K_{ij} - wL_j]\dot{s}_j - \Sigma_{j \in k}\Sigma_i r_i \dot{\sigma}_{ij}$$

The first term can be interpreted as a structural change effect, contributing to productivity growth through the activation of profitable sectors or the inactivation of unprofitable vectors. The second term translates into productivity effects the reduction of idle resources.

The constant price input-output tables obtained from Statistics Canada are expressed in 1961 prices from 1962 to 1971, in 1971 prices from 1971 to 1981, in 1981 prices from 1981 to 1986, and in 1986 prices from 1986 to 1991. All tables have been converted to 1986 prices using the chain rule. For reasons of confidentiality, the tables contain missing cells, which we have filled using the following procedure. The vertical and horizontal sums in the make and use tables are compared with the reported line and column totals, which do contain the missing values. We select the rows and columns where the two figures differ by more than 5% from the reported totals, or where the difference exceeds $250 million. We then fill holes or adjust cells on a case by case basis filling in priority the intersections of the selected rows and columns, using the information on the input or output structure from other years, and making sure the new computed totals do not exceed the reported ones.

There are three capital types, namely buildings, equipment, and infrastructure.[5] The gross capital stock, hours worked and labor earnings are from the KLEMS database of Statistics Canada, described in Johnson (1994). In particular, corrections have been made to include in labor the earnings of the self-employed, and to separate business and non-business labor and capital. The total labor force figures are taken from Cansim (D767870) and converted in hours using the number of weekly hours worked in manufacturing (where it is the highest). Out of the 50 industries, no labor nor capital stock data exist for sectors 39, 40, 48, 49, 50, and no capital stock data for industry 46. The capital stock for industry 46 has been constructed using the capital/labor ratio of industry 47 (both industries producing predominantly the same commodity).

The international commodity prices are approximated by the U.S. prices, given that 70% of Canada's trade is with the United States. We have used the U.S. producer prices from the U.S. Bureau of Labor Statistics, Office of Employment Projection. The 169 commodity classification has been bridged to Statistics Canada's 94 commodity classification. To convert U.S. prices to Canadian equivalents, we have used, whenever available, unit value ratios, (UVRs, which are industry specific) computed and kindly provided to us by Gjalt de Jong (1996). The UVRs are computed using Canadian quantities valued at U.S. prices. For the other commodities, we have used the purchasing power parities computed by the OECD (which are based on final demand categories). The UVRs establish international price linkages for 1987, the PPPs for 1990 in terms of

[5]Statistics Canada calls them "building constructions," "equipment" and "engineering constructions." Alternatively we could have modeled capital as being sector-specific, the so called putty-clay model. We prefer the present hypothesis of sectoral mobility of capital within each group for three reasons. First, to let the economy expand, we would have needed capacity utilization rates which are badly measured and unavailable for a number of service sectors. Second, to relieve a numerical collinearity problem, we would have to relieve the capital constraint on the non-business sector. Third, the combination of 11 non-tradeables and sector-specific capacity expansion limits is too stringent. It would lead to a high shadow price on construction commodities and zero shadow prices almost anywhere else.

Canadian dollars per U.S. dollar. We hence need two more transformations. First, U.S. dollars are converted to Canadian dollars using the exchange rates taken from Cansim (series 0926/B3400). Second, since the input-output data are in 1986 prices, we need the linkage for 1986, which is computed by using the respective countries' commodity deflators: the producer price index for the U.S. (see above) and the total commodity deflator from the make table (except for commodities 27, 93 and 94, for which we use the import deflator from the final demand table) for Canada. Finally, international commodity prices are divided by a Canadian final demand weighted average of international commodity prices to express them in real terms.

Are considered as non-tradeable, services incidental to mining, residential construction, non-residential construction, repair construction, retail margins, imputed rent from owner occupied dwellings, accommodation & food services, supplies for office, laboratories & cafetaria, and travel, advertising & promotion, for which no trade shows up in the input-output tables for most of the sample period.

The structure of some non-tradeability constraints implies the equality of the activity levels of "construction" and final demand, "owner-occupied dwellings" and final demand, and "printing and publishing" and "travel, advertising and promotion." We have forced the activity level of industry 39 (government royalties on natural resources, which essentially pertains to oil drigging in Alberta) to follow industry 5 (crude petroleum and natural gas) to ensure there are no such royalities without oil drigging. A more detailed documentation of the data and their construction is available from the authors upon request.

4 Results

The linear program was solved for each year from 1962 to 1991 yielding the optimal activity levels and shadow prices for the TFP-expressions.

Table 1 contains the shadow prices of labor (in 1986 \$/hour), of the three types of capital, and of the trade deficit (the latter four are in 1986\$/1986\$, that is rates of return) from 1962 to 1991. Labor was worth at the margin \$16.13 in 1986 prices in 1962. Its productivity followed an increasing trend until 1982 and then a bumpy road ending at \$46.13 in 1991. The rate of return on buildings followed a downward trend, dropping to zero in 1982, sharply rebounded in 1984, and then dropped again to reach zero from 1988 on. In other words, there were excess buildings in 1982 and in 1988-1991. Equipment was not fully utilized until 1983 and again in 1988, 1990 and 1991. Comparing the evolutions of their shadow prices, labor, buildings and equipment seem to be substitutes. Infrastructure had an increasing rate of return until 1974, much greater than the other two types of capital, and then a declining productivity until the end of our period. On average over the 1962-1991 period, a dollar increase in the trade deficit allowed final demand to buy 64 cents. (Final demand does not increase by the full dollar because of the need to produce locally non-tradeable commodities for a given commodity composition of final demand.) Its shadow price was pretty stable until 1981 and more volatile and somewhat lower after 1981.

Following the conception proposed in this paper, to consider TFP-growth as the sum of factor productivity growths where the latter are determined by the Lagrange multipliers of the endowment constraints, Table 2 shows TFP-growth by factor input. In the first period, 1962-1974, TFP grows a healthy 2.6 percent a year.[6] The second period, 1974-1981, shows the notorious slowdown, in fact a negative TFP-growth of -0.5 percent a year. The last period, 1981-1991, TFP rebounced to 3.8 percent a year. The bulk of TFP-growth is attributed to labor, next to nothing to the trade deficit, and the remainder to capital. In the first period the 2.6% TFP-growth consists of 2.4% labor productivity growth and 0.2% capital productivity growth, according to the first column of Table 2. The latter is distributed very unevenly over the three types of capital, with infrastructure picking up 1.1%, equipment none, and buildings plummeting by -0.9%. The slowdown in the second period is ascribed to both labor (dropping to 0.5% a year) and capital (turning -1.0% a year). Once more, infrastructure is decisive, explaining all of the negative productivity growth. The successful TFP-growth in the last period is a labor story. Labor productivity growth was a dramatic 5% a year, offsetting a reduction in capital productivity growth of 1% a year. Again, the latter is determined by the productivity of infrastructure.

While Table 2 shows the composition of TFP-growth by factor input, Table 3 decomposes it into the three sources of structural change, namely technical change, the terms-of-trade effect and the shift in preferences. The first line of Table 3 is identical to the first line of Table 2. In the first period the bulk of TFP-growth (2.6%) is caused by technical change (the Solow residual at shadow prices is 1.7%). The TFP slowdown in the second period is also ascribed to a downturn in technology. The recovery in the last period, however, is due not only to a Solow residual (at shadow prices) increase of one percent, but above all to an improvement in the terms-of-trade effect from 0.5 to 3.8% annually. It might look strange to have some negative Solow residuals, albeit at shadow prices. How can technology regress? There are at least two serious explanations to it. First, technical progress does not show in the statistics right away. This is the argument raised by David (1990) to explain the productivity paradox. It takes time to absorb the new information technology and to use it to its maximal efficiency, just as it took time to adjust to electricity at the beginning of the century. Second, the final demand structure might move in a direction so different from the evolution of the primary inputs structure that the production possibility frontier (Figure 1) moves inwards. Nevertheless, traditional

[6] According to Bergeron, Fauvel and Paquet (1995), Canada hit a recession from January 1975 to March 1975, from May 1980 to June 1980, from August 1981 to November 1982, and from April 1990 to March 1991. We chose the breakpoints before the slump years 1975 and 1982 to compare productivity performances as much as possible over comparable phases of the business cycles.

Solow residual analysis would indicate positive TFP growth rates if the economy was at the same time moving closer to the frontier.

It is interesting to contrast our measure of technical change with the traditional Solow residual, which we have added to Table 3. The distinction of our measures is that prices are endogenous, to ensure that they reflect marginal productivities, whereas the traditional Solow residual is calculated using observed, market prices. It makes quite a difference if one uses market prices instead of shadow prices, as the second and last lines of Table 3 reveal. The market-price based Solow residual is fairly unbiased in the period 1962-1974, but overstates the role of technical change in the periods 1974-1981 and 1981-1991. The terms-of-trade effect was far more important in explaining total factor productivity growth, particularly in the 1980s.

5 Conclusion

Standard measures of TFP-growth hinge on the use of value shares, hence of factor input prices. Since the latter are presumed to match factor productivities, the standard procedure amounts to accepting at face value what is supposed to be measured. In this paper we have determined factor productivities as the Lagrange multipliers to the program that maximizes the level of domestic final demand. The consequent measure of total factor productivity growth encompasses not only the Solow residual, but also terms-of-trade and preference-shift effects.

Canadian TFP-growth is U-shaped over the 1960s, 70s and 80s. The bulk of it is labor productivity growth and the remainder capital productivity growth. Of the latter, the infrastructure component is the main determinant. The healthy initial TFP-growth and the slowdown are caused by technical change, but the recovery is due not only to a Solow residual increase, but above all to an improvement in the terms-of-trade effect.

6 References

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Table 1: **Factor productivities (shadow prices)**

Year	Labor	Buildings	Equipment	Infrastructure	Debt
1962	16.13	0.32	0.00	0.20	0.71
1963	16.50	0.33	0.00	0.19	0.71
1964	17.46	0.26	0.00	0.22	0.69
1965	17.86	0.28	0.00	0.18	0.69
1966	18.28	0.28	0.00	0.18	0.69
1967	19.31	0.20	0.00	0.18	0.68
1968	20.38	0.21	0.00	0.17	0.67
1969	20.91	0.17	0.00	0.18	0.67
1970	20.40	0.19	0.00	0.23	0.68
1971	21.78	0.14	0.00	0.24	0.66
1972	22.44	0.08	0.00	0.28	0.66
1973	22.96	0.05	0.00	0.32	0.65
1974	23.24	0.01	0.00	0.47	0.61
1975	22.70	0.05	0.00	0.45	0.64
1976	23.61	0.12	0.00	0.37	0.64
1977	24.52	0.08	0.00	0.34	0.65
1978	24.83	0.07	0.00	0.31	0.65
1979	24.85	0.06	0.00	0.32	0.65
1980	24.60	0.07	0.00	0.28	0.66
1981	24.31	0.10	0.01	0.25	0.69
1982	29.66	0.00	0.00	0.18	0.57
1983	12.07	0.62	0.83	0.15	0.82
1984	12.22	0.49	1.03	0.11	0.81
1985	23.11	0.24	0.22	0.16	0.73
1986	20.09	0.18	0.83	0.05	0.72
1987	20.76	0.11	0.99	0.03	0.70
1988	44.11	0.00	0.00	0.01	0.31
1989	22.41	0.00	1.21	0.00	0.63
1990	44.33	0.00	0.00	0.01	0.32
1991	46.13	0.00	0.00	0.01	0.29

Table 2: **Productivity growth (annualized percentages) by factor input**

	1962-1974	1974-1981	1981-1991
Total	2.6	-0.5	3.8
Labor	2.4	0.5	5.0
Capital	0.2	-1.0	-1.1
Buildings	-0.9	0.4	-0.3
Equipment	0.0	0.1	0.3
Infrastructure	1.1	-1.5	-1.2
Deficit	-0.0	0.0	-0.1

Table 3: **Productivity growth (annualized percentages) by source of structural change**

	1962-1974	1974-1981	1981-1991
Total	2.6	-0.5	3.8
Technical change	1.7	-1.3	-0.3
Terms-of-trade effect	0.7	0.5	3.8
Preference shift	0.2	0.3	0.2
Solow residual at market prices	1.4	0.5	0.2

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